FINAL REPORT

PHYSICAL AND CHEMICAL CHARACTERIZATION OF STREAMS AND RIVERS WITHIN DENALI NATIONAL PARK AND PRESERVE

By

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January 22, 1998

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ABSTRACT

This report describes methods and results from an interdepartmental/interagency (USDA Forest Service/USDI National Park Service) cooperative study performed in 1994-1997 in Denali National Park and Preserve. Water samples were collected from streams and rivers throughout the park and preserve to develop a set of baseline data describing the physical and chemical conditions of surface waters. Samples were collected from both clear and glacier-fed streams.

Field measurements included pH, electrical conductivity, total dissolved solids, dissolved oxygen (DO), temperature, and stream discharge. Laboratory analyses were performed for pH, electrical conductivity, chloride (Cl), nitrate nitrogen (NO_3-N), sulfate (SO_4), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), ammonium (NH_4), dissolved organic carbon (DOC), alkalinity, turbidity, and suspended sediment.

Mean pH and alkalinity values were significantly different ($\alpha=0.05$) for the north side versus south side samples. Conductivity values were significantly higher for streams on the north side of the park when compared to those on the south side of the Alaska Range. On the north side, mean concentrations of most ions were relatively comparable for glacier-fed and clear water streams. Significant differences were observed on the south side between glacier-fed and clear water sites for many of the analytes.

Significant differences in water chemistry between the north and south sides and in suspended sediment and turbidity for glacially-influenced streams may reflect differences in geology between the north and south sides of the Alaska Range. Neither suspended sediment nor turbidity differed significantly between the north and south side clear water streams. Flow was correlated only weakly to suspended sediment and turbidity for both glacier-fed and clear water streams, regardless of whether they were located on the north or south side of the park.

Streams in the Kantishna Hills that have been affected by mining activities were sampled to determine the level of recovery that may be occurring since mining ceased. Average turbidity and suspended sediment levels were extremely low in almost all cases, and they were very similar for both mined and undisturbed streams. Turbidity levels recorded on mined streams in 1979, 1982, and 1983 studies are considerably greater than those observed on the same streams during 1994-1996. Lack of mining-related activities and regrowth of vegetation in disturbed areas probably accounts for most of the change.

This report also includes recommendations for long-term monitoring. Water chemistry data from selected watersheds in the designated wilderness, on the south side, and in areas subject to future disturbance will be essential components of the park's Long-Term Ecological Monitoring program.

INTRODUCTION

The need to conduct a comprehensive, problem-oriented research program that would provide management with factual knowledge about water resources in Denali National Park and Preserve is identified in the Draft Resources Management Plan. The objectives of this inventory were to:

1. Obtain baseline water chemistry information from a variety of watersheds in Denali National Park and Preserve.

2. Determine present condition and level of recovery since 1985 in streams in the Kantishna Hills that were placer mined as recently as the early 1980s.

3. Select individual watersheds that may be representative and suitable for long-term monitoring.

Establishing water chemistry profiles of streams in Denali National Park and Preserve provides essential baseline information for future management decisions. While one watershed near the park headquarters area (Rock Creek) is being studied in detail, investigations of other watersheds are essential to document whether water resources have changed or do change over time. Some watersheds near park and preserve boundaries are subject to development proposals that may affect water quality. Surface waters of the south slope of the Alaska Range, in particular, had not been studied prior to 1994.

Water resources in the Kantishna Hills area were studied in some detail soon after the park was expanded in 1980. These studies primarily investigated the effects of placer mining on water quality. However, events during the 1980s effectively ended active placer mining in the Kantishna Hills. On July 22, 1985, the U.S. District Court for Alaska enjoined the National Park Service (NPS) from approving plans of operations for mining in National Park System units in Alaska. The court order directed full compliance with the National Environmental Policy Act and the Mining in the Parks Act (P.L. 94-429) in reviewing proposed mining operations. In addition, the court called for preparation of an Environmental Impact Statement evaluating the cumulative effects of mining in Denali National Park and Preserve.

A Record of Decision (ROD) was signed by the Regional Director on August 21, 1990. Alternative D as presented in the Final Environmental Impact Statement was selected, calling for acquisition of all mining claims. Interim actions outlined in the ROD require processing of mining plans of operations until acquisition is completed. Current water quality information is essential to complete the required environmental analysis when a mining plan of operations is received.

Because of current regulations governing approval of mining plans of operations, it is likely that land acquisition rather than placer mining will be the dominant activity in Kantishna during the next several years. As the NPS acquires former mining claims where major surface disturbance has occurred, well-planned reclamation efforts will be needed. Water chemistry data will be important in this effort. Water quality research needs in the Kantishna Hills today include detailed information on watersheds for which mining plans of operations are likely to be received and

documentation of recovery from past placer mining.

This report describes methods and results from an interdepartmental/interagency (USDA Forest Service/USDI National Park Service) cooperative inventory performed in 1994-1996 in Denali National Park and Preserve. Water samples were collected from streams and rivers throughout the park and preserve from May through October 1994-1996 to develop a set of baseline data describing the physical and chemical conditions of surface waters. Samples were collected from both clear and glacier-fed streams. On the north side of the park 32 clear streams were sampled at 53 different sites, and 11 glacier-fed streams were sampled at 14 different sites. On the south side 11 clear streams were sampled at 13 different sites, and 8 glacier-fed streams were sampled at 11 different sites. There were a total of 67 sites on the north side and 24 sites on the south side (Figs. 1-3).

Two sites along the Nenana River near the main park entrance area were sampled and are included in the data base but not the enclosed analyses, since the sampling sites are just outside the park boundary. A site on Long Creek in Denali State Park has been included in the analyses because of its proximity to the national park and because of the need for baseline data in that area.

Analyses were done in both the field and the laboratory. Laboratory analyses were performed at the U.S. Forest Service Timber and Watershed Laboratory in Parsons, West Virginia. Field measurements included pH, electrical conductivity, total dissolved solids, dissolved oxygen (DO),

Legend

Sampling Sites

Watersheds

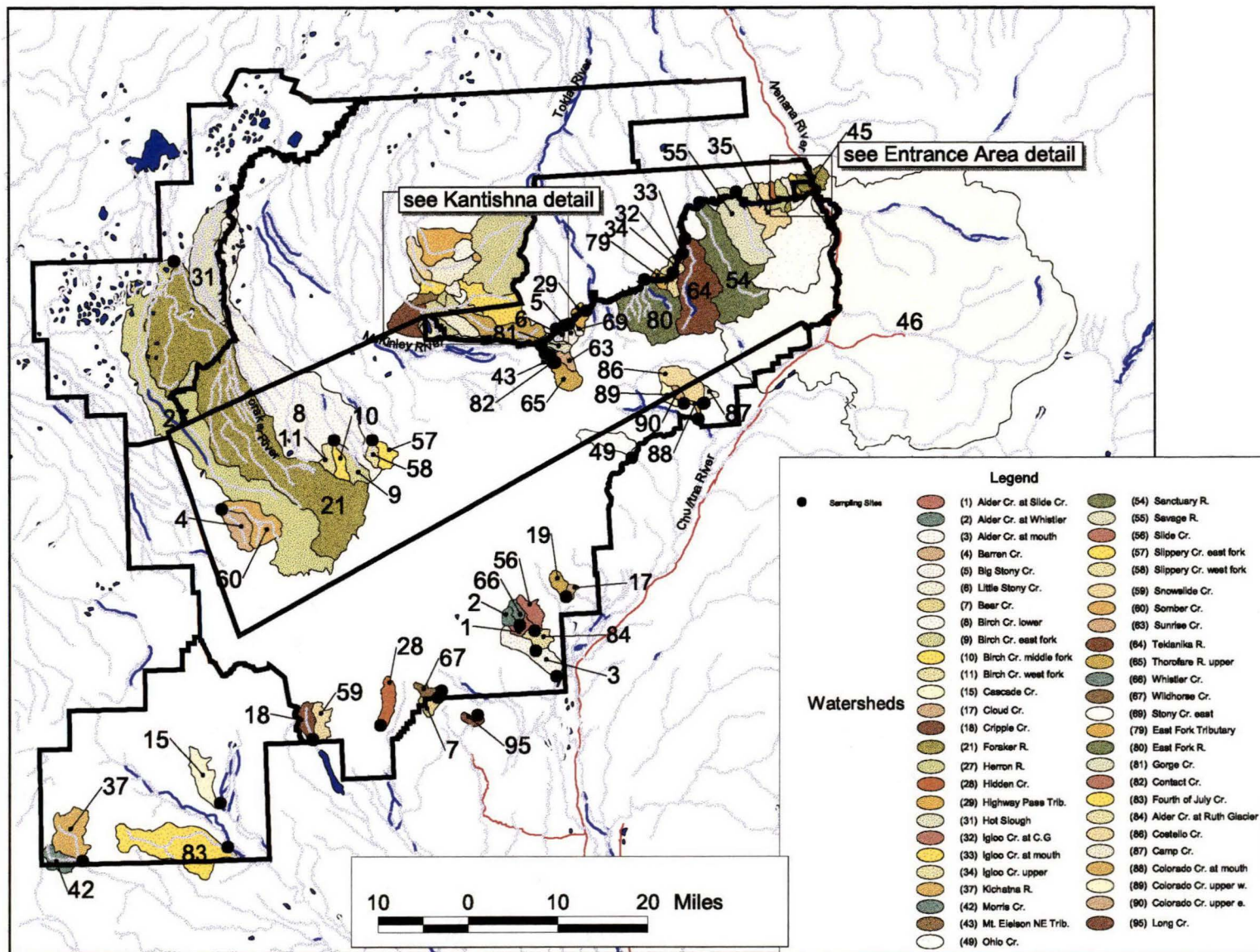|	
(1) Alder Cr. at Slide Cr.	(54) Sanctuary R.
(2) Alder Cr. at Whistler	(55) Savage R.
(3) Alder Cr. at mouth	(56) Slide Cr.
(4) Barren Cr.	(57) Slippery Cr. east fork
(5) Big Stony Cr.	(58) Slippery Cr. west fork
(6) Little Stony Cr.	(59) Snowslide Cr.
(7) Bear Cr.	(60) Somber Cr.
(8) Birch Cr. lower	(63) Sunrise Cr.
(9) Birch Cr. east fork	(64) Teklanika R.
(10) Birch Cr. middle fork	(65) Thorofare R. upper
(11) Birch Cr. west fork	(66) Whistler Cr.
(15) Cascade Cr.	(67) Wildhorse Cr.
(17) Cloud Cr.	(69) Stony Cr. east
(18) Cripple Cr.	(79) East Fork Tributary
(21) Foraker R.	(80) East Fork R.
(27) Herron R.	(81) Gorge Cr.
(28) Hidden Cr.	(82) Contact Cr.
(29) Highway Pass Trib.	(83) Fourth of July Cr.
(31) Hot Slough	(84) Alder Cr. at Ruth Glacier
(32) Igloo Cr. at C.G	(86) Costello Cr.
(33) Igloo Cr. at mouth	(87) Camp Cr.
(34) Igloo Cr. upper	(88) Colorado Cr. at mouth
(37) Kichatna R.	(89) Colorado Cr. upper w.
(42) Morris Cr.	(90) Colorado Cr. upper e.
(43) Mt. Eielson NE Trib.	(95) Long Cr.
(49) Ohio Cr.	

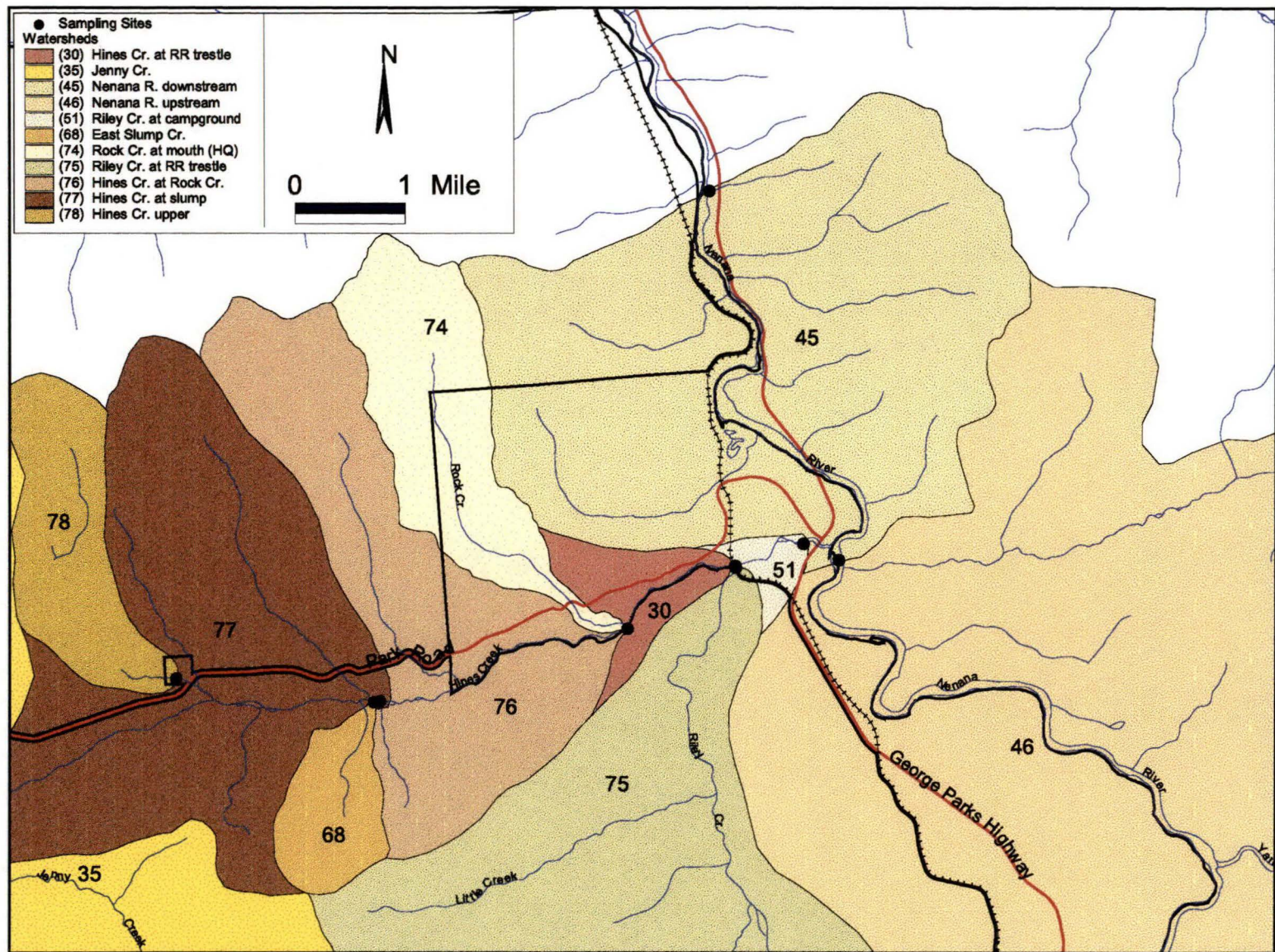Figure 1. Watersheds selected for sampling in Denali National Park and Preserve, 1994-1996

Figure 2. Watersheds selected for sampling in Denali National Park and Preserve, 1994-1996 (Entrance Area Detail).
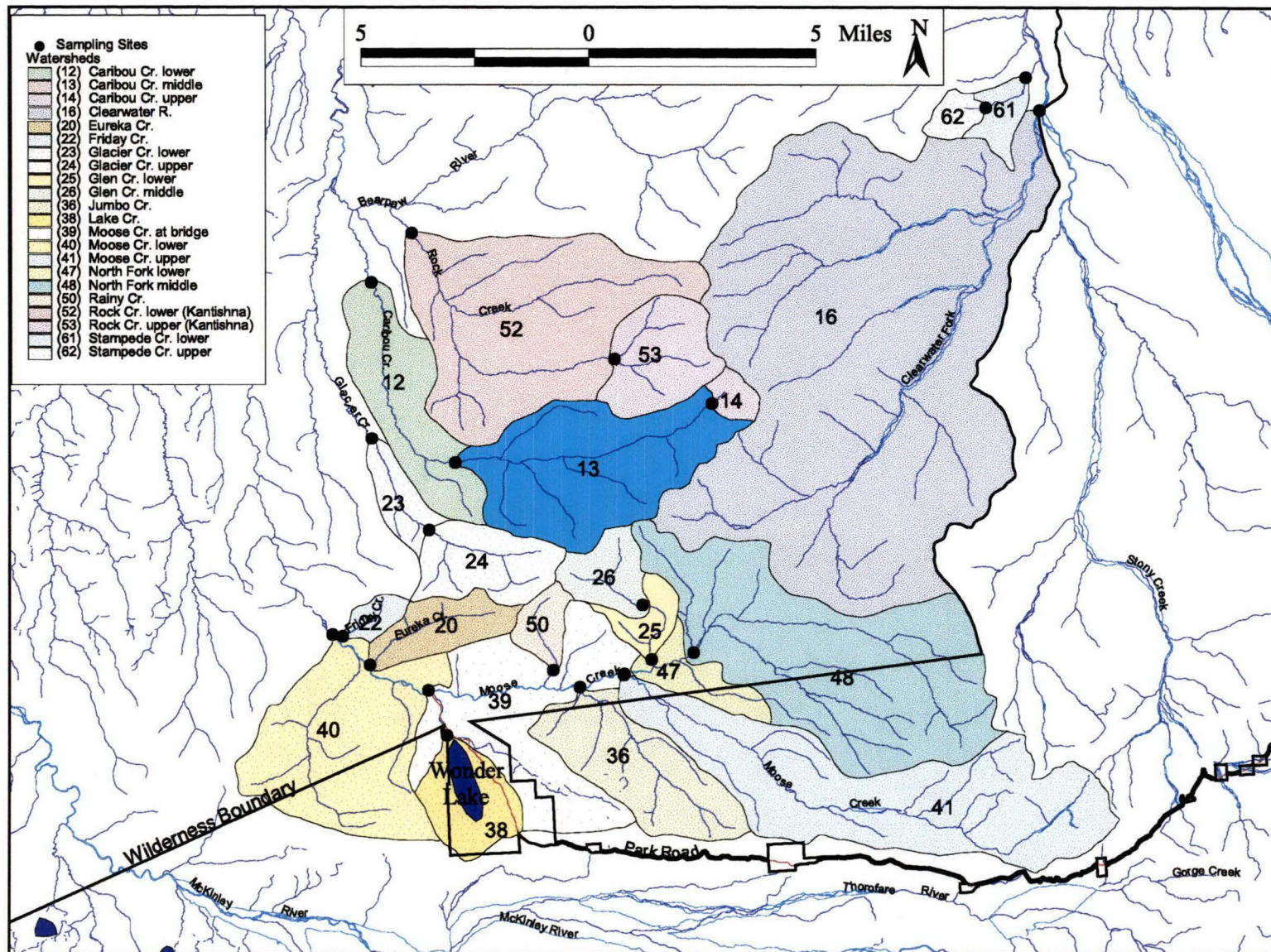
Figure 3. Watersheds selected for sampling in Denali National Park and Preserve, 1994-1996 (Kantishna Area Detail)

temperature, and stream discharge. Laboratory analyses were performed for pH, electrical conductivity, chloride (Cl), nitrate nitrogen (NO_3-N), sulfate (SO_4), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), ammonium (NH_4), dissolved organic carbon (DOC), alkalinity, turbidity, and suspended sediment. Sampling and analyses were conducted according to the Draft Protocols for Long-Term Ecological Monitoring of Stream Channel Reference Sites: Channel Morphometry and Water Chemistry, Denali National Park and Preserve (National Park Service 1997). Protocols for sample handling and analyses also are summarized in this current report.

Field work was coordinated with a park-wide benthic macroinvertebrate study being conducted by Alexander Milner and Sarah Roberts. Results of data analysis to-date indicate that watersheds in Denali National Park and Preserve can be classified into at least eight clearly identifiable groups based on differences in benthic macroinvertebrate communities. These groups are defined by key determinants of benthic macroinvertebrate production, such as concentration of chlorophyll 'a', nitrate concentrations, channel stability, turbidity, and other water chemistry components. Use of detailed water chemistry data along with replicated invertebrate sampling should make it possible to produce a predictive model for Denali, with potential applications throughout interior Alaska.

LITERATURE REVIEW

The effects of placer mining on surface water quality have been well documented. According to Madison (1981), the primary effect is increased sediment loading of streams and the subsequent

effects on the stream ecosystem. Additional effects include increased organic loading in the stream system, increased minor element content, potential for acid drainage, and impacts on fish and other aquatic biota. Madison (1981) recommended that additional site-specific, short-term studies be conducted to document the effects of individual mining operations. Such studies are available for some streams in Denali National Park.

Several comprehensive water quality investigations were conducted in the Kantishna Hills during the early 1980s and reviewed by Deschu (1985). General knowledge was that placer mining operations would continue. Meyer and Kavanaugh (1983) provided a thorough description of Kantishna area streams and conducted in-depth studies on selected streams to document effects of placer mining on fish resources. West and Deschu (1984) completed a 2-year study of heavy metals in the Kantishna Hills area to document the effects of placer mining on the available concentrations of heavy metals in streams. Sexton (1983) investigated Kantishna streams receiving effluent discharge from active placer gold mining operations and assessed the effects of these operations on water quality. The effectiveness of mitigation measures being used also was analyzed.

The concept of aquatic ecosystem recovery after placer mining was addressed by Oswood and Wedemeyer (1990), who called for long-term monitoring of inactive mine sites to assess the rate of recovery after mining disturbance. Their research emphasized macroinvertebrates, especially in Slate and Eldorado Creeks. An investigation of how heavy metals (primarily antimony, arsenic, and manganese) from antimony mines affected the stream ecosystems of Slate and Eldorado

Creeks had been conducted earlier (Wedemeyer, 1987). Heavy metals were found to enter Stampede Creek also, but this was attributed to mineralization since no mining activity was underway. Jumbo Creek was used as an unmined control stream. Van Maanen and Solin (1988) documented physical characteristics of Kantishna area streams and noted limited changes in physical properties of streams attributable to mining. One exception was the modification of Rainy Creek to construct settling ponds.

Karle et al. (1996) described streambed disturbances during and after the restoration of Glen Creek in 1991-1992. Restoration had short-term negative effects, but stream conditions stabilized within two years of restoration based upon analysis of stream morphometry (Karle et al. 1996) and invertebrates (Major 1996).

Other research projects have attempted to address inventory and monitoring needs. These efforts generally have been limited to the Rock Creek watershed. For example, Stottlemyer (1992) looked at changes in upstream-downstream water chemistry and terrestrial vitrification and nitrogen mineralization. Hanneman (1993) sampled for heavy metals in Rock Creek and noted that high alkalinity concentrations appear to be precipitating heavy metals, thereby decreasing dissolved metal concentrations in stream water.

Only one more general inventory and monitoring or baseline type study has been identified. Stottlemyer and McLoone (1993) studied several small watersheds to establish baseline surface water quality data and to document natural factors affecting water chemistry, especially

parameters having the most potential value as indicators of ecosystem change. The current inventory follows from these identified needs, and it expands the baseline data to include a variety of watersheds on both the north and south slopes of the Alaska Range.

METHODS

Sampling Locations

Samples were collected at 91 sites in streams and rivers in Denali National Park and Preserve (Table 1). Samples also were collected at two sites on the Nenana River, which forms part of the eastern boundary of the park, and from one site on Long Creek in Denali State Park, a location of planned facility development. Both glacier-fed and clear water streams and rivers were sampled. In this report, a clear water stream or river is one that is not influenced by glacial melt water. Glacier-fed streams and rivers are those in which glacial melt waters contribute to streamflow; however, clear water tributaries also may contribute to the streamflow of glacier-fed systems. Sampling sites were classified by their position relative to the Alaska Range. Those north of the range are referred to as north side sites, and those south of the Alaska Range are referred to as south side sites.

When possible, sites were sampled three or more times each season to survey conditions under varying flow regimes. Because of logistical and budgetary constraints, repeated sampling was difficult at some of the more-remote sites in the national preserve and on the south side of the Alaska Range. While small sample sizes limited the types of statistical analyses that could be conducted for some watersheds, the data set as a whole represents a wide variety of watersheds and flow regimes in the national park and preserve.

Table 1. Streams and rivers sampled in Denali National Park and Preserve, 1994-1996.

Stream or River	North (N) or South (S) side	Clear (C) or Glacier-fed (G)	Number of samples
Alder Creek at Slide Creek	S	G	4
Alder Creek at Whistler Creek	S	G	4
Alder Creek at Mouth*	S	G	8
Barren Creek	N	C	5
Big Stony Creek	N	C	10
Little Stony Creek	N	C	9
Bear Creek	S	C	9
Birch Creek Lower	N	G	5
Birch Creek East Fork	N	G	5
Birch Creek Middle Fork	N	C	5
Birch Creek West Fork	N	C	5
Caribou Creek Lower	N	C	5
Caribou Creek Middle	N	C	3
Caribou Creek Upper	N	C	5
Cascade Creek	S	C	5
Clearwater River	N	C	4
Cloud Creek	S	C	7
Cripple Creek	S	G	7
Crystal Creek	S	C	7
Eureka Creek	N	C	6
Foraker River	N	G	5
Friday Creek	N	C	6
Glacier Creek Middle	N	C	5

Stream or River	North (N) or South (S) side	Clear (C) or Glacier-fed (G)	Number of samples
Glacier Creek Upper	N	C	5
Glen Creek Lower	N	C	9
Glen Creek Middle	N	C	8
Herron River	N	G	5
Hidden Creek	S	G	8
Highway Pass Tributary	N	C	10
Hines Creek at Railroad Trestle*	N	C	10
Hot Slough	N	C	5
Igloo Creek at Campground*	N	C	11
Igloo Creek at Mouth	N	C	10
Igloo Creek Upper	N	C	11
Jenny Creek	N	C	8
Jumbo Creek	N	C	8
Kichatna River	S	G	4
Lake Creek	N	C	5
Moose Creek at Bridge*	N	C	8
Moose Creek Lower	N	C	7
Moose Creek Upper	N	C	8
Morris Creek	S	C	3
Mt. Eielson Northeast Tributary	N	C	1
Nenana River Downstream	N	G	11
Nenana River Upstream	N	G	11
North Fork Lower	N	C	8
North Fork Middle	N	C	3
Ohio Creek	S	G	3
Rainy Creek	N	C	8

Stream or River	North (N) or South (S) side	Clear (C) or Glacier-fed (G)	Number of samples
Riley Creek at Campground	N	C	11
Rock Creek Lower (Kantishna)	N	C	5
Rock Creek Upper (Kantishna)	N	C	5
Sanctuary River*	N	C	9
Savage River	N	C	13
Slide Creek	S	C	3
Slippery Creek East Fork	N	G	6
Slippery Creek West Fork	N	G	6
Snowslide Creek	S	G	7
Somber Creek	N	G	4
Stampede Creek Lower	N	C	3
Stampede Creek Upper	N	C	3
Sunrise Creek	N	G	7
Teklanika River	N	G	10
Thorofare River Upper*	N	G	6
Whistler Creek	S	G	5
Wildhorse Creek	S	C	9
Slump Creek East	N	C	3
Stony Creek East	N	C	1
Little Stony Creek West	N	C	1
Little Stony Creek East	N	C	1
Toklat River East Branch	N	G	1
Toklat River West Branch	N	G	1
Rock Creek at Mouth (Headquarters)	N	C	6
Riley Creek at Railroad Trestle	N	C	7
Hines Creek above Rock Creek	N	C	7
Hines Creek at Slump	N	C	6

Stream or River	North (N) or South (S) side	Clear (C) or Glacier-fed (G)	Number of samples
Hines Creek Upper*	N	C	7
East Fork Tributary	N	C	6
East Fork River	N	G	4
Gorge Creek	N	C	4
Contact Creek	N	C	6
Fourth of July Creek	S	G	4
Alder Creek above Ruth Glacier	S	G	5
Costello Creek	S	C	4
Camp Creek	S	C	4
Colorado Creek at Mouth	S	C	4
Colorado Creek Upper West Fork	S	C	3
Colorado Creek Upper East Fork	S	C	3
Moose Creek Upper near Cabin	N	C	1
Igloo Creek Upper at Closure	N	C	1
Jumbo Creek Upper West Fork	N	C	1
Highway Pass Creek at Mouth	N	C	1
Long Creek (Denali State Park)*	S	C	3

*Indicates Hydrolab monitoring site

Seven of the sampling sites were selected for more detailed field investigation using a Hydrolab H20 multi-parameter data logger. Temperature, pH, dissolved oxygen, turbidity, specific conductance, percent saturation, and total dissolved solids were measured over different 24-hour periods. This data set provided some insight into diurnal characteristics of the streams and baseline inventory in areas of potential development (appendix A).

In some cases, samples were collected at more than one location on a stream, while in others only one sample was collected. In the latter case, sampling usually was done at the mouth of the stream or just upstream from a major confluence. A complete description of many of the field locations can be found in the field and office notes, and photographic documentation was made of most sites.

Field Methods

Discharge

Instantaneous discharge was gauged when extreme depth and/or velocity did not prohibit safe measurement. Throughout each summer, discharge from the larger streams and rivers could not be measured. In some other streams, velocity could be measured on some, but not all sampling dates due to significant changes in discharge over time. A missing discharge value in the data set indicates that velocity could not be measured.

To measure discharge, a tape was stretched across the stream, and depth and velocity were measured at 0.6-depth levels using a Swoffer wading rod and current meter. Typically, readings were made at 0.5-ft (0.15-m) or 1.0-ft (0.30-m) intervals and occasionally at 2-ft (0.61-m) intervals on wide streams. When the transect was wider than 50 ft (15.24 m), a 100-m (328.1-ft) tape was used, so that readings were made at 0.5-m (1.64-ft) or 1.0-m (3.28-ft) intervals. The use of metric intervals was noted in the field notes for proper conversion so discharge could be calculated in cubic feet per second (cfs). Except in very narrow streams, such as Rainy Creek, at least 20 cross-sectional measurements were collected for each transect.

Where possible, transects were located where all streamflow was confined within a single channel. In some systems, particularly higher-order rivers, braided channels could not be avoided, so depth and velocity were recorded across a transect in each braid. Discharge from all braids was summed to determine total discharge for the river (Figs. 4-5).

Field Chemistry and Physical Conditions

Upstream from the discharge transect, stream temperature, electrical conductivity, total dissolved solids (TDS), pH, and dissolved oxygen (DO) were measured in the field. Temperature, conductivity, and TDS were measured with a Hach Model 44600 meter (Hach 1989). DO was measured with a Hach Model 16046 meter (Hach 1989) and pH was measured with a hand-held wand-type pH meter. Because of harsh field conditions, several different pH meters were used; Cole Parmer and Corning pH wands were used most of the time.

Conductivity, TDS, and temperature were determined by immersing the conductivity cell directly into the stream water near the water's edge, but in the active current. After allowing the meter a few minutes to stabilize, the reading for each parameter was recorded in the field notebook. Temperature was recorded in °C, conductivity in μS cm^{-1} or mS cm^{-1}, depending upon the conductivity, and TDS in mg L^{-1} or g L^{-1}, also depending upon the conductivity. TDS by the Hach method is defined as one-half of the conductivity value (Hach 1989), so it is a calculated value, rather than a directly-measured one. The conductivity cell was calibrated at the beginning of the sampling season and occasionally throughout the season using 1000 ppm NaCl solution (Hach 1989). Meter calibration generally was stable over relatively long periods.

Figure 4. Measuring discharge in the Sanctuary River, Denali National Park, May 1995.

Figure 5. Measuring discharge in Highway Pass Creek, June 1994.

Dissolved oxygen was measured at the same location by immersing the DO probe directly into the stream water. The meter was calibrated prior to each day's use, according to the manufacturer's instructions, using barometric pressure, air temperature, and altitude if barometric pressure was for an altitude other than sea level (Hach 1989). New filling solution and a new membrane were installed when the meter became erratic or sluggish. Because of the large size of the measuring instrument, dissolved oxygen was not recorded for some streams that were accessible only by long hikes.

At the beginning of each sampling day, the pH wand was calibrated according to the manufacturer's instructions. Most of the pH wands required two-point calibrations using pH 7 and 4 buffers. One of the backup wands used a single-point calibration using a pH 7 buffer. In general, field pH wands that measured to hundredth units were employed, but one of the backup wands measured only to tenth pH units.

Stream pH was determined by collecting a stream sample in a 250-ml high-density polyethylene (HDPE) bottle at the location where the other parameters were measured. The bottle and cap were rinsed three times with stream water. Then the bottle was filled and capped. The pH wand was rinsed in the stream and rinsed with about 200 ml of sample from the bottle. The wand was immersed in the bottle in the remaining sample until a stable reading was obtained, and the reading was recorded.

Sample Collection

Samples were collected and stored in HDPE bottles for laboratory analysis. Bottles were chemically cleaned prior to use by hand washing with laboratory-grade detergent, rinsing with tap water, and finally rinsing with distilled water (Edwards and Wood 1993). Bottle washing was done by U.S. Forest Service personnel in West Virginia. Acid washed bottles were not used because subsequent chemical determinations did not include heavy metals.

Three samples were collected at each stream. One sample was collected in a 250-ml bottle for pH, electrical conductivity, and alkalinity analyses. Another sample was collected in a separate 250-ml bottle for suspended sediment and turbidity analyses, and a third sample was collected in a 1-L bottle for ionic chemistry analyses. Each sample bottle was labeled with the sampling location, date, time, and aliquot identification prior to collecting the samples.

The pH/conductivity/alkalinity aliquot was collected directly from the stream after rinsing the bottle and cap three times with the sample. The suspended sediment/turbidity sample was collected proportionately with flow using a DH-81 suspended sediment sampler. The DH-81 bottle was rinsed three times with stream water, and then a sample was collected along the stream transect from which velocity and depth were measured. The sample was transferred to the second 250-ml bottle after rinsing the bottle three times with the sample. The sample was agitated during all rinsing and sample transference to keep sediment suspended.

The third aliquot for chemistry was filtered by hand-vacuum pumping through one or more 0.45-μm membrane filters, depending upon turbidity levels. The filtering apparatus (Nalgene 310) and the filter were rinsed initially with stream water; the stream rinse water was discarded. Then the sample was filtered. The initial 30 to 50 ml of filtered sample was used to rinse the 1-L storage bottle. After rinsing the bottle and cap with the filtered sample and discarding it, the remaining filtered sample was collected in the bottle. If more than one filter was needed because of high sediment or organic levels, each filter was rinsed prior to use. The samples were refrigerated after collection and then shipped by priority mail with ice packs to the U.S. Forest Service Timber and Watershed Laboratory (TWS) in Parsons, West Virginia for analyses.

Sample Preparation and Analysis

Immediately upon receipt at the laboratory, the filtered samples were separated into aliquots for analyses of major anions (sulfate, nitrate, and chloride), major base cations (calcium, magnesium, potassium, and sodium), ammonium, and dissolved organic carbon. Aliquots were stored in prewashed 50-ml polypropylene centrifuge tubes. Acid preservatives were added to some of the aliquots, according to EPA/TWS laboratory protocols (Edwards and Wood 1993). Base cation aliquots were acidified with nitric acid to pH < 2, and the ammonium/DOC aliquots were acidified to pH < 2 with sulfuric acid. No preservatives were added to the anion, pH/conductivity/alkalinity, or suspended sediment/turbidity aliquots; the latter two were stored in the bottles in which they were shipped. All aliquots, except the major cations and suspended sediment/turbidity were stored at 4°C until analysis. Analyses were performed using the methods, protocols, and equipment indicated in Table 2.

Table 2. Analytical equipment and methodology for laboratory analysis.

Aliquot	Preservation	Instrumentation	Holding Time
. . . . Filtered			
DOC	Acidify to pH 2 with H_2SO_4 Store at 4°C	Dohrmann 80 carbon analyzer	14 days
NH_4	Acidify to pH 2 with H_2SO_4 Store at 4°C	Wescan ammonia analyzer	7 days
Cations	Acidify to pH 2 with HNO_3 Store at room temperature	Fisons direct current plasma spectrometer (1994-1995) Perkin Elmer 503 atomic absorption spectrophotometer (1996)	56 days
Anions	Store at 4°C	Dionex ion chromatograph	7 days
. . . . Unfiltered			
pH	Store at 4°C	Fisher 915 pH meter with combination electrode	7 days
Electrical conductivity	Store at 4°C	Radiometer CDM83 conductivity meter with platinum cell	14 days
Alkalinity	Store at 4°C	Radiometer VIT90 video titrator	14 days
Suspended sediment	Store at room temperature	Vacuum filtration through Whatman GF/C filters	No limits
Turbidity	Store at room temperature	Hach ratio turbidity meter	No limits

In addition to the chemical and physical determinations for each stream, aquatic fungi isolates were collected on membrane filters during the 1994 and 1995 field seasons. Three replicate filters were obtained at each site, by hand-vacuum filtering approximately 250-ml of stream water per filter. The filters were stored in petri dishes and air dried. A few drops of a blue lactic acid preservative solution were applied to a small percentage of the filters in the field in 1994 to eliminate the need for air drying. However, air drying was found to preserve the samples better and permit easier identification of the fungi, so air drying was used as the primary preservation method. Filtering for aquatic fungi at each site was done prior to filtering for chemistry. This process maximized the amount of rinsing to which each filtration apparatus was subjected, thereby reducing the potential of chemical contamination among streams. Fungi filters were sent to Dr. Tara Dubey in Chicago, Illinois for fungal species identification and enumeration. Fungal results are not discussed in this report.

Statistical Analyses

To examine differences that exist between the north and south sides of the park and preserve, some analyses involved comparisons of data collected between the two areas. Also, because of the inherent differences between glacier-fed streams and clear water streams, some of the analyses were performed separately for streams that were glacier-fed or clear.

Prior to 1985, placer mining disturbed many streams in the Kantishna Hills area of Denali National Park. In the early 1980s, significant concern was expressed in internal park reports about the

potential long-term effects of that mining on stream chemistry and sediment loads. Consequently, comparisons between the mined and unmined streams in the Kantishna Hills were made to examine if the long-term deleterious conditions anticipated in these reports were detectable. Data from water chemistry studies conducted between 1979 and 1987 in the Kantishna Hills were compared with the 1994-1996 data to provide an indication of recovery rates in mined streams.

In general, field electrical conductivity and pH results compared very well to those same measurements made in the laboratory. However, pH and/or conductivity were not measured in the field at all locations during every site visit, so laboratory pH and conductivity (which were measured for each sample) results were used in all statistical analyses. Because pH is a logarithmic function, direct means of pH cannot be calculated and compared. Therefore, analyses involving pH were done on hydrogen ion concentrations and then converted back and expressed as pH.

Statistical analyses were performed using PC SAS (SAS Institute Inc. 1988). Even though many of the sites were sampled repeatedly over time, the minimal number of repeat samples prohibited the use of time series analyses. Consequently, data were analyzed using other methods, such as t-tests and correlation matrices.

RESULTS AND DISCUSSION

Alkalinity and pH

Overall, most pH values were in the pH 7.51-8.00 range (Table 3). With the exception of 41 samples collected over all three field seasons, all samples were alkaline (i.e., pH > 7.0). Streams with pH values < 7, Alder Creek Middle, Alder Creek Upper, Alder Creek at Mouth, Bear Creek, Cascade Creek, Cloud Creek, Cripple Creek, Crystal Creek, Hidden Creek, Kichatna River, Slide Creek, Snowslide Creek, Whistler Creek, Wildhorse Creek, Camp Creek, West Fork Upper Colorado Creek, Long Creek, and West Fork Birch Creek, were at or above pH 6.37. This latter value was the lowest single laboratory pH recorded and was for Cripple Creek on June 6, 1996. In 1994 and 1995, a total of 22 acidic samples (< pH 7.00) were collected, and all were from streams in the south side of the park and preserve (Fig. 1). In 1996, 19 acidic samples were collected. That year, a single sample from the north side, West Fork of Birch Creek, had a pH < 7.00.

Forty-nine sites had at least one sample collected from them that was strongly alkaline (i.e., pH > 8.00); these 49 sites resulted in a total of 163 observations with pH > 8.00 (Table 3). All of the strongly alkaline streams were on the north side of the park and preserve (Fig. 1), except Bear Creek (7/28/1995) and East Fork of Upper Colorado Creek (9/11/1995). The highest pH of any sample collected was 9.05 from Little Stony Creek (8/26/1996).

The mean pH of north side sites was significantly higher at 7.77 than 7.00 for the south side (Table 4). The distribution of pH values for individual samples (Fig. 6) as well as for the average annual pH of each stream (Fig. 7) reflect this difference. The majority of samples and streams on the north side of the park and preserve had pH values ≥7.51, whereas on the south side pH values were predominantly≤ 7.50.

Table 3. Frequency distribution of pH observations from Denali National Park and Preserve stream and river water samples.

pH Range	Number of Occurrences	Percent of Occurrences
< 7.01	41	8.13
7.01 - 7.50	105	20.83
7.51 - 8.00	195	38.69
> 8.00	163	32.34

Table 4. pH and alkalinity (mg $CaCO_3$ L^{-1}) means, minimums, and maximums for north and south side streams in Denali National Park and Preserve in 1994-1996. All north and south side means significantly different at $\alpha=0.05$.

Parameter	North			South		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
pH	7.77	6.84*	9.05	7.00	6.37	8.23#
Alkalinity	112.74	19.25^	353.80	22.75	2.35	114.05

*North side samples with pH < 7.00: West Fork of Birch Cr. 5/31/1996.

#South side samples with pH > 8.00: Bear Cr. 7/28/1995, East Fork Upper Colorado Cr. 9/11/1995.

^North side samples with alkalinity <25.0: West Fork of Birch Cr. 5/31/1996, Little Stony Cr. 8/29/1996.

Alkalinity concentrations likewise reflect north and south side differences. As expected from the pH values, streams in the north side were much more strongly buffered (Table 4) than those on the south side. North side stream alkalinities averaged 112.74 mg $CaCO_3$ L^{-1} compared to 22.75 mg $CaCO_3$ L^{-1} for the south side. Alkalinity distributions of individual samples (Fig. 8) and of the averages of each sampling site by year (Fig. 9) show virtually identical patterns. Only a
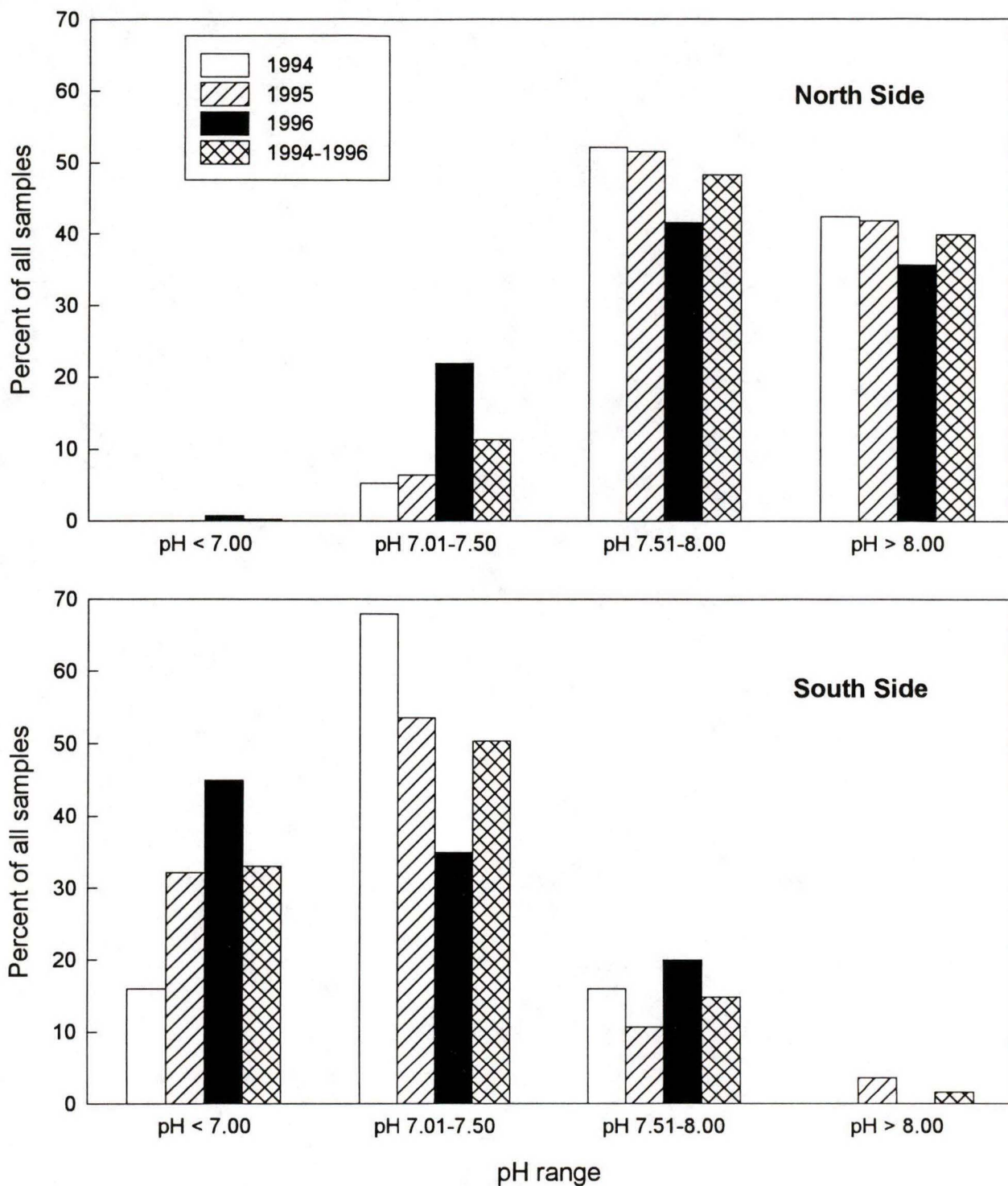
Figure 6. Percent distribution of pH values for all individual samples collected from north and south side streams and rivers, by year and for all years combined.

Figure 7. Percent distribution of average annual pH values for each stream and river sampled on the north and south side, by year and for all years combined.

Figure 8. Percent distribution of alkalinity values for all individual samples collected from north and south side streams and rivers, by year and for all years combined.

Figure 9. Percent distribution of average annual alkalinity values for each stream and river sampled on the north and south side, by year and for all years combined.

small percentage of the north side individual or average values had alkalinities less than 51 mg $CaCO_3$ L^{-1} (Figs. 8-9). The distribution of percentages on the north side was close to normally distributed, with the greatest number of observations and sites occurring in the 101-150 mg $CaCO_3$ L^{-1} range. In contrast, in the south sidealkalinity values for almost all of the individual samples and site alkalinity averages were in the 0-50 mg $CaCO_3$ L^{-1} range (Figs. 8-9). Alkalinities < 25 mg $CaCO_3$ L^{-1} were observed only on the south side (Table 5), except one observation on the West Fork of Birch Creek (5/31/1996) and one on Little Stony Creek (8/29/1996). These low alkalinities mean there is little residual buffering capacity in these streams.

Carbonaceous marine sediments and platform deposits dominate the north side geology, while shallow, sandy turbidites and acidic igneous intrusions are more common on the south side of the park. These geologic differences most likely contribute significantly to the pH and alkalinity differences observed on the north and south sides of the Alaska Range.

Electrical Conductivity, Ionic Chemistry, and DOC

Electrical conductivity, which is a measure of total dissolved solids, was extremely variable across the sites sampled. However, the distribution of conductivities of both the individual observations and site averages were substantially different between the north and south sides (Figs. 10-11). On the south side conductivity values were almost exclusively < 250 μS cm^{-1}, while in the north conductivity values fell most frequently between 251 and 500 μS cm^{-1}, but were spread somewhat evenly over the 0-750 μS cm^{-1} range. Consequently, conductivity values were statistically higher for north side sites compared to the south side (Table 6). Mean

Table 5. Stream or river locations for which alkalinities < 25 mg CaCO$_3$ L^{-1} were observed, and the corresponding alkalinity values. Multiple values indicate results from different sampling dates.

| Site	Alkalinity Values							
	------------------------------- mg CaCO$_3$ L^{-1} -----------------------------							
Alder Cr. Middle	20.02	19.99	18.65	20.18				
Alder Cr. Upper	22.40							
Alder Cr. at Mouth	16.39	18.10	19.71	15.46	19.14	19.74	23.61	23.43
Little Stony Cr.*	22.33							
Bear Cr.	20.47	21.94	23.79	15.59	24.32	21.80	23.75	
W. Fork Birch Cr.*	19.25							
Cascade Cr.	16.13	12.74	10.66	10.00	13.20			
Cloud Cr.	14.29	15.38	10.10	15.92	16.99	12.53	12.45	
Cripple Cr.	6.94	3.36	5.80	6.08	6.60	2.70	6.00	
Crystal Cr.	6.29	7.55	7.35	6.77	8.60	7.38	7.62	
Hidden Cr.	11.43	11.55	15.05	8.06	8.74	8.39	15.19	10.95
Kichatna R.	16.34	19.56	8.90					
Morris Cr.	24.00							
Slide Cr.	9.33	9.58	8.69					
Snowslide Cr.	3.50	2.35	2.84	2.58	3.01	2.67	3.14	
Whistler Cr.	21.58	19.84	24.68	20.09				
Wildhorse Cr.	14.04	20.78						
Fourth of July Cr.	18.85	20.91	23.14	21.85				
Alder Cr. above Ruth Glacier	10.42	14.31	18.06	13.78				
Camp Cr.	19.41	14.02	24.44					
Long Cr.	20.42	13.46	11.54					

*North side streams.
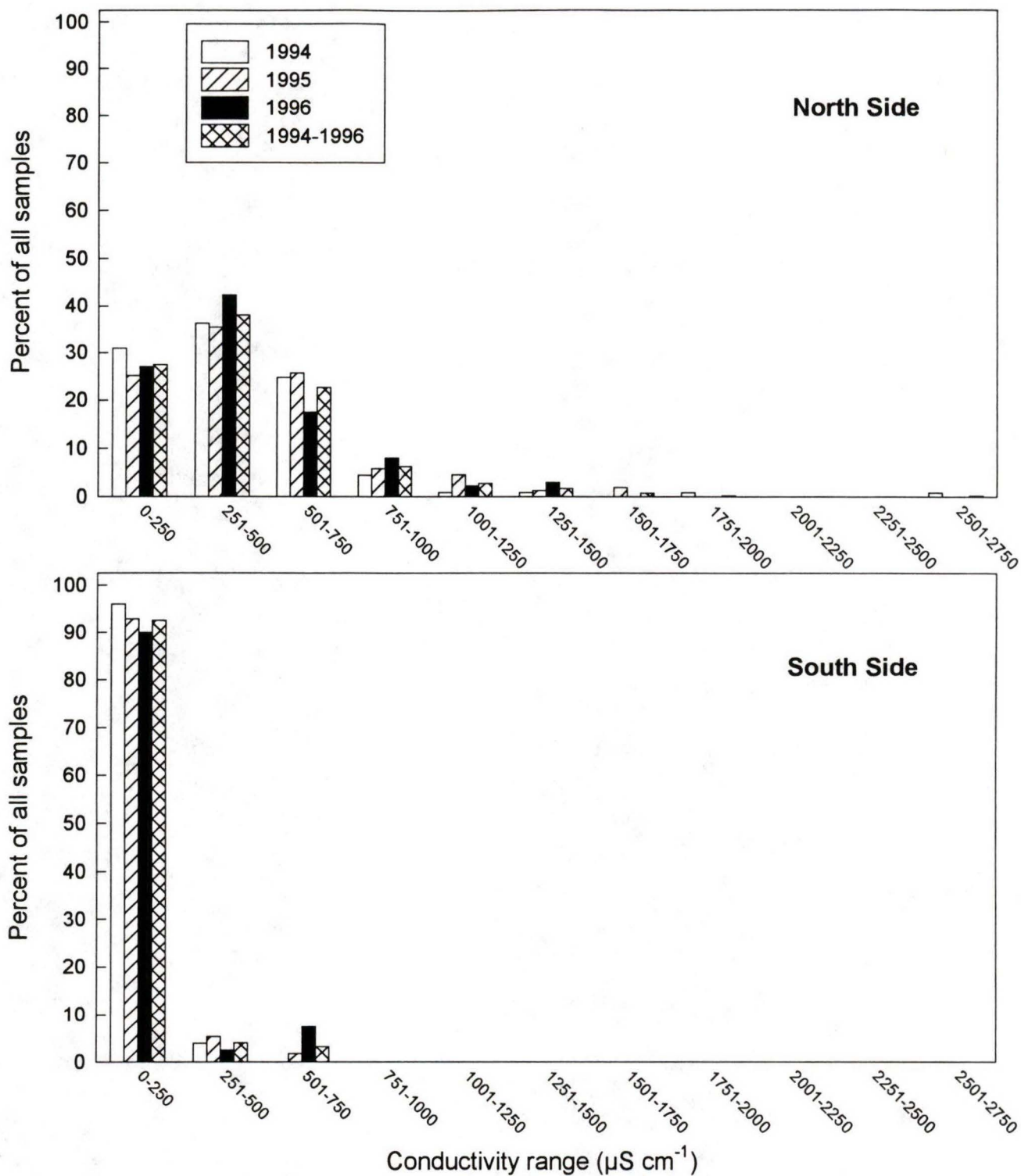
Figure 10. Percent distribution of conductivity values for all individual samples collected from north and south side streams and rivers, by year and for all years combined.
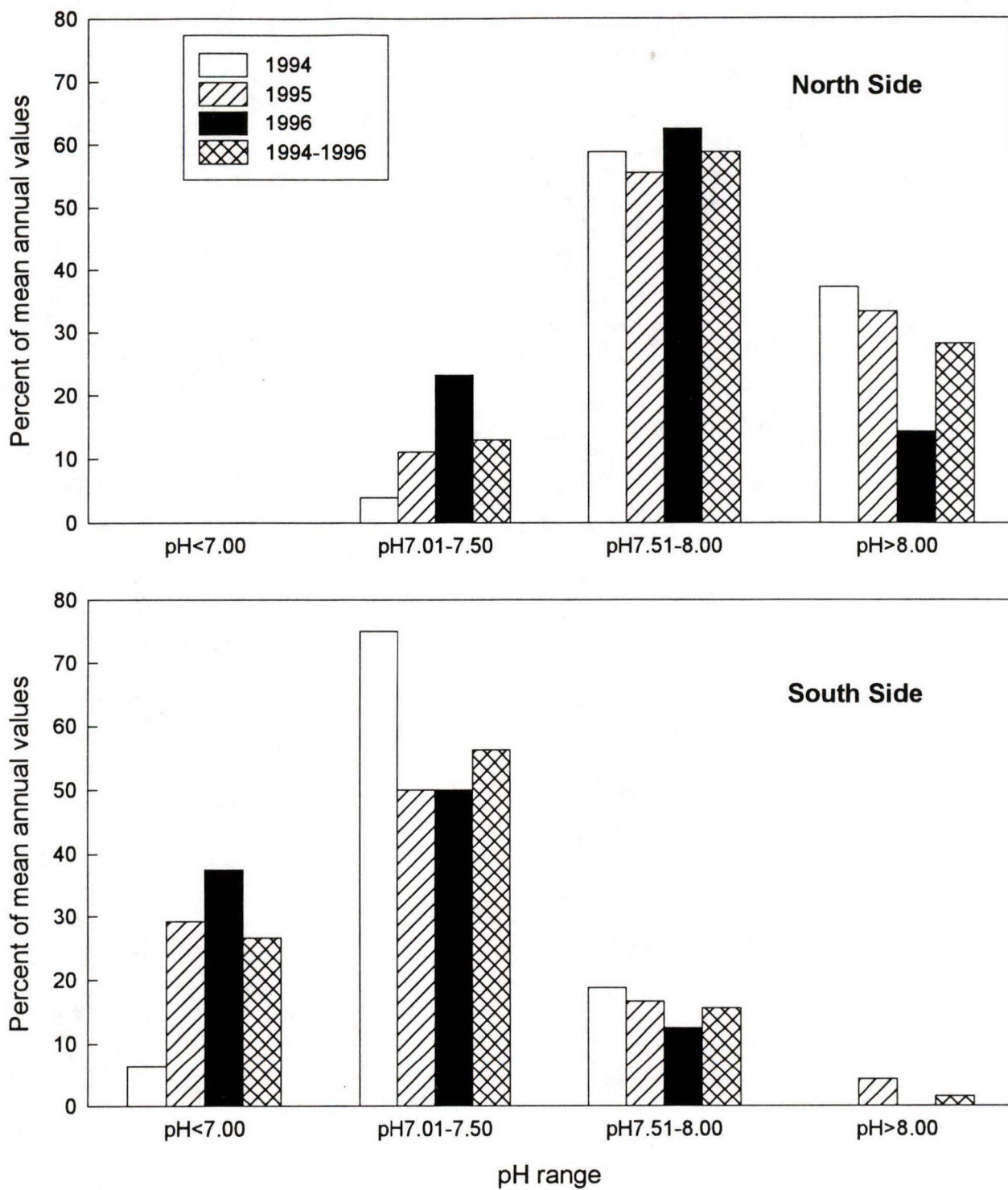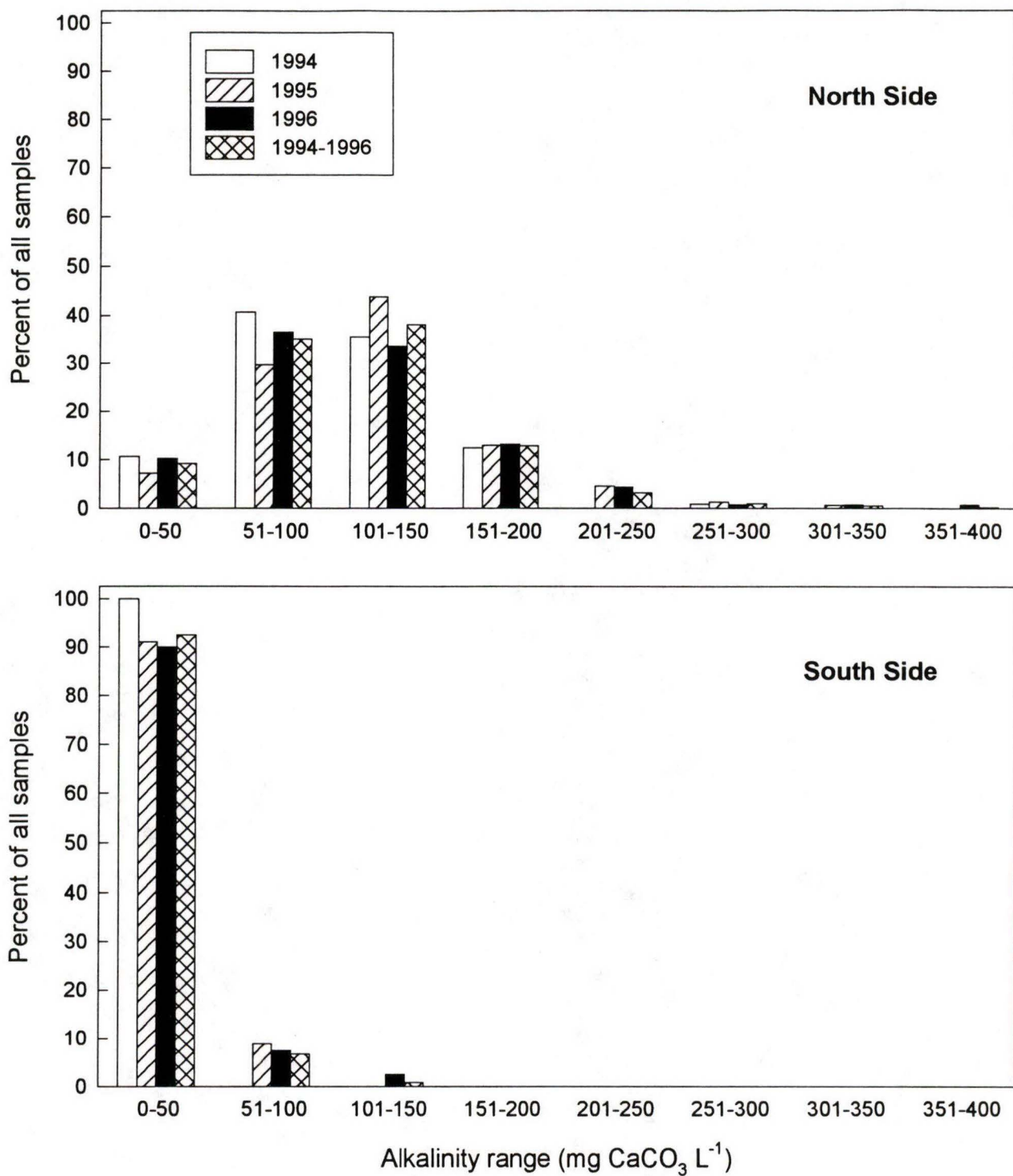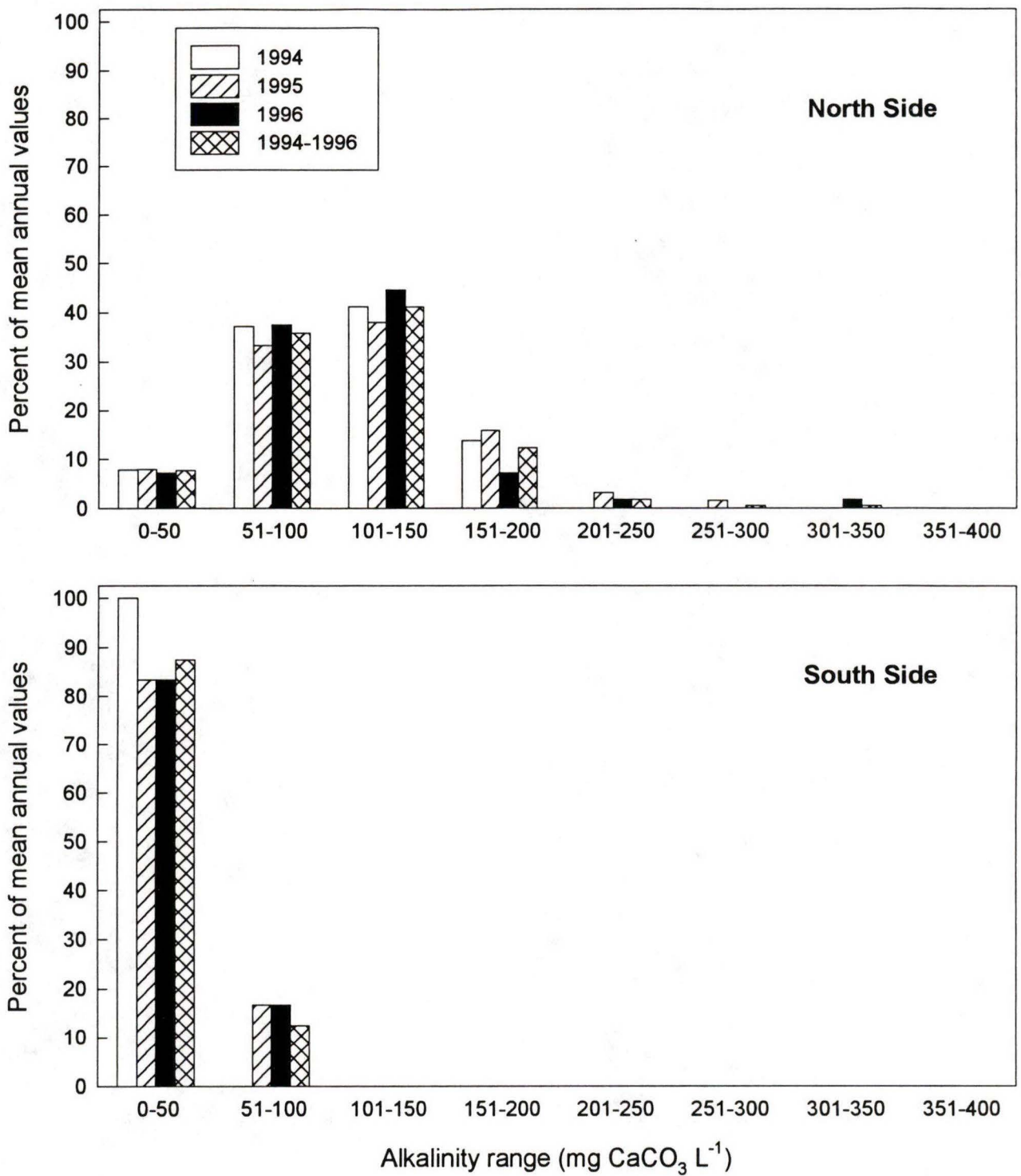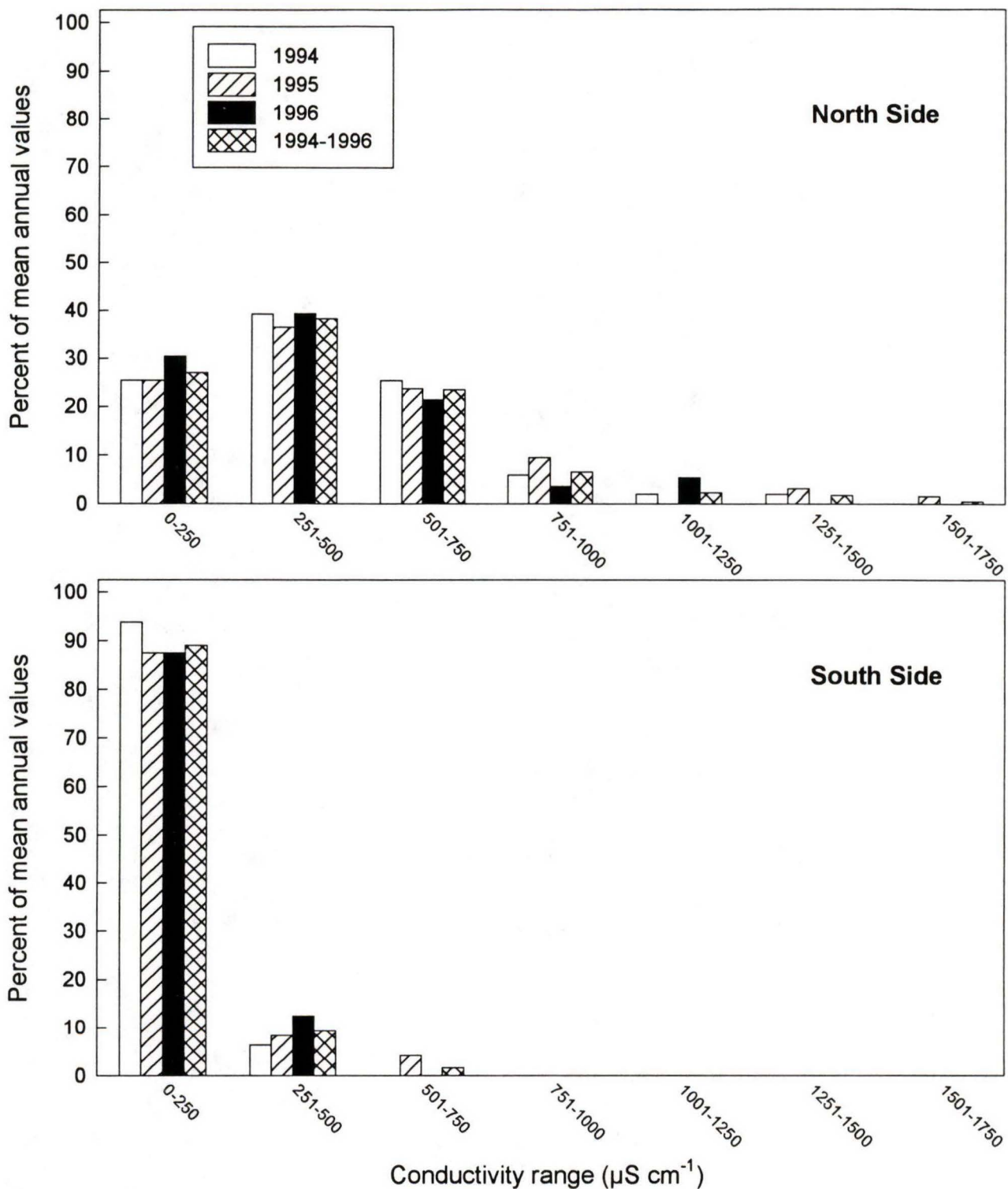
Figure 11. Percent distribution of average annual conductivity values for each stream and river sampled on the north and south side, by year and for all years combined.

Table 6. Mean analyte concentrations and standard deviations for north and south side streams and rivers by year and for all years combined. Units are mg L^{-1}, except conductivity which is μS cm^{-1}.

Year	Analyte	North Mean	North Std. Dev.	South Mean	South Std. Dev.
All yrs:	Conductivity**	465.55	311.50	91.41	115.47
	Chloride**	0.72	1.69	0.13	0.15
	Nitrate**	0.75	0.54	0.21	0.29
	Sulfate**	144.16	172.70	20.90	42.13
	Calcium**	51.06	28.38	9.14	8.52
	Magnesium**	25.50	32.49	4.02	8.59
	Sodium**	6.72	8.61	1.57	2.32
	Potassium**	1.20	0.79	0.64	1.09
	DOC**	6.39	7.31	2.03	1.69
1994:	Conductivity**	445.59	339.10	65.17	55.87
	Chloride**	0.49	0.53	0.13	0.03
	Nitrate**	0.69	0.44	0.18	0.21
	Sulfate**	140.80	223.46	11.26	19.64
	Calcium**	49.33	31.07	7.62	5.68
	Magnesium**	19.50	28.51	1.67	2.45
	Sodium**	6.32	9.33	0.89	0.31
	Potassium**	1.49	1.08	0.53	0.29
	DOC*	4.00	7.11	2.47	2.18
1995:	Conductivity**	489.32	316.43	86.96	113.99
	Chloride**	0.69	0.77	0.12	0.13
	Nitrate**	0.82	0.60	0.19	0.27
	Sulfate**	154.86	166.45	19.56	40.49
	Calcium**	51.46	27.25	8.05	7.14
	Magnesium**	30.08	38.26	4.13	9.31
	Sodium**	6.41	6.48	1.52	2.30
	Potassium	1.08	0.53	0.74	1.58
	DOC**	7.49	8.99	1.61	1.12
1996:	Conductivity**	454.33	281.54	114.05	140.67
	Chloride**	0.93	2.72	0.16	0.21
	Nitrate**	0.72	0.54	0.26	0.34
	Sulfate**	134.93	129.12	28.44	52.34
	Calcium**	52.02	27.48	11.51	10.96
	Magnesium**	25.20	27.52	5.28	9.74
	Sodium**	7.38	9.99	2.03	2.90
	Potassium**	1.12	0.70	0.58	0.34
	DOC**	7.10	4.41	2.33	1.89

**North and south side means significantly different at α=0.05.
*North and south side means significantly different at α=0.10.

conductivity values over all three years combined for north and south side sites were 465.55 and 91.41 μS cm^{-1}, respectively. The lowest conductivity recorded was 9.40 μS cm^{-1} for Snowslide Creek on 7/15/1995, and the highest was 2620 μS cm^{-1} for Big Stony Creek on 9/1/1994.

Not surprisingly considering the conductivity results, all mean analyte concentrations were consistently greater for north side streams than for south side streams (Table 6). All differences were significant at α=0.05, except dissolved organic carbon (DOC) in 1995 which was significant at α=0.10, and potassium in 1995 which was not significant. Since the potential exists for glacier-fed and clear water streams to have substantially different chemistry and for one type of stream to dominate the comparisons in Table 6, similar statistical comparisons were made between north and south side glacier-fed streams (Table 7), and north and south side clear water streams (Table 8). These results indicate that both glacier-fed and clear water streams and rivers on the north side had significantly higher conductivity and ionic concentrations than those on the south; thus, the differences seen for the entire data set (Table 6) are not dependent upon stream type. Instead, the difference in bedrock chemistry between the north and south sides seems to be the primary factor controlling stream chemistry. Greater ionic dissolution and resulting conductivity on the north side probably are associated with more basic marine and more easily weathered volcanic rock, while the lower ionic dissolution and conductivity on the south side probably are associated with the more acidic igneous plutons and the less carbonaceous marine rock in that part of the park.

Table 7. Mean analyte concentrations and standard deviations for north and south side glacier-fed streams and rivers by year and for all years combined.

Year	Analyte	North Mean	North Std. Dev.	South Mean	South Std. Dev.
		--- mg L^{-1} ---			
All yrs:	Chloride**	1.39	3.64	0.10	0.09
	Nitrate**	0.52	0.37	0.33	0.31
	Sulfate**	119.77	133.33	10.64	11.23
	Calcium**	49.60	28.81	7.49	5.32
	Magnesium**	17.92	17.71	1.35	1.78
	Sodium**	6.57	5.39	0.80	0.30
	Potassium**	1.45	0.73	0.61	0.32
	DOC**	5.34	4.72	1.45	1.28
1994:	Chloride**	0.50	0.62	0.12	0.02
	Nitrate**	0.53	0.37	0.30	0.17
	Sulfate**	123.49	120.49	11.26	12.75
	Calcium**	45.02	26.92	7.63	4.22
	Magnesium**	17.00	14.09	1.26	1.39
	Sodium**	6.23	4.99	0.84	0.24
	Potassium**	1.59	0.75	0.66	0.28
	DOC	4.08	7.61	2.43	2.51
1995:	Chloride**	0.92	1.01	0.09	0.10
	Nitrate**	0.54	0.41	0.25	0.31
	Sulfate**	139.79	165.61	9.56	10.46
	Calcium**	52.71	28.64	6.43	5.04
	Magnesium**	20.70	23.11	1.25	1.58
	Sodium**	6.47	5.98	0.73	0.31
	Potassium**	1.33	0.57	0.56	0.34
	DOC**	6.02	1.97	1.11	0.49
1996:	Chloride**	2.51	5.76	0.11	0.10
	Nitrate	0.48	0.35	0.46	0.36
	Sulfate**	98.46	108.40	11.85	11.81
	Calcium**	50.12	30.90	8.96	6.17
	Magnesium**	16.03	14.36	1.55	2.29
	Sodium**	6.92	5.27	0.89	0.29
	Potassium**	1.45	0.86	0.66	0.33
	DOC**	5.64	3.65	1.35	0.51

**North and south side means significantly different at α=0.05.

Table 8. Mean analyte concentrations and standard deviations for north and south side clear water streams and rivers by year and for all years combined.

Year	Analyte	North Mean	North Std. Dev.	South Mean	South Std. Dev.
		mg L^{-1}			
All yrs:	Chloride**	0.54	0.53	0.16	0.19
	Nitrate**	0.82	0.56	0.10	0.21
	Sulfate**	150.33	181.56	30.36	55.96
	Calcium**	51.84	28.43	10.67	10.47
	Magnesium**	27.47	35.04	6.49	11.27
	Sodium**	6.79	9.31	2.27	3.05
	Potassium**	1.16	0.79	0.67	1.48
	DOC**	6.69	7.87	2.56	1.85
1994:	Chloride**	0.49	0.51	0.13	0.04
	Nitrate**	0.73	0.45	0.07	0.18
	Sulfate**	145.02	242.42	11.25	24.94
	Calcium**	50.34	32.02	7.61	6.94
	Magnesium**	20.09	31.00	2.05	3.15
	Sodium**	6.35	10.10	0.93	0.36
	Potassium**	1.46	1.14	0.41	0.25
	DOC	3.98	7.04	2.51	1.93
1995:	Chloride**	0.61	0.59	0.15	0.15
	Nitrate**	0.90	0.61	0.12	0.22
	Sulfate**	155.88	167.88	29.56	54.97
	Calcium**	51.81	27.18	9.68	8.55
	Magnesium**	32.05	40.80	7.00	12.53
	Sodium**	6.38	6.70	2.32	3.06
	Potassium	1.02	0.48	0.92	2.21
	DOC**	7.92	9.96	2.12	1.35
1996:	Chloride**	0.49	0.47	0.19	0.26
	Nitrate**	0.79	0.56	0.09	0.21
	Sulfate**	148.28	133.44	42.14	67.51
	Calcium**	53.17	26.75	13.62	13.50
	Magnesium**	28.35	29.91	8.36	12.27
	Sodium**	7.66	11.09	2.98	3.68
	Potassium**	1.05	0.62	0.52	0.34
	DOC**	7.57	4.59	3.14	2.22

**North and south side means significantly different at $\alpha=0.05$.

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Even though the north versus south side statistical tests had the same results whether the entire data set was used or whether it was divided into glacier-fed and clear water systems, some chemical differences between stream types existed. On the north side, mean concentrations of most ions were relatively comparable for glacier-fed and clear water streams (Table 9). However, significant differences in many major concentrations between glacier-fed and clear water sites were present for the south side (Table 10). Average concentrations of the glacier-fed sites often were half or less of the corresponding concentrations of the clear water sites, except for nitrate which was three times higher for the glacier-fed sites. The lithological differences mentioned above also may account for these observations.

Correlation matrices were developed between chemical constituents to identify ion pairings in order to interpret possible mineralogical characteristics among the four stream types (i.e., north glacier-fed, north clear, south glacier-fed, south clear). Instantaneous discharge also was included in the matrices. Data from all three years were combined to maximize the sample size for each analysis. Correlation matrices for individual years are not discussed within the text because the combined years results are more meaningful for examining general ecosystem relationships over time.

No ion concentrations were correlated strongly to instantaneous discharge (Tables 11-14), indicating that neither concentration nor dilution processes were prevalent with flow increases. In systems dominated by baseflow sources (even during stormflow), concentrations often are not

Table 9. Mean analyte concentrations for Denali National Park and Preserve north side clear water and glacier-fed streams and rivers for 1994-1996.

Analyte	Clear water		Glacier-fed	
	Mean	Std. Dev.	Mean	Std. Dev.
	------------------------------- mg L^{-1} -------------------------------			
Chloride*	0.54	0.53	1.39	3.64
Nitrate**	0.82	0.56	0.52	0.37
Sulfate	150.33	181.56	119.77	133.33
Calcium	51.84	28.43	49.60	28.81
Magnesium**	27.47	35.04	17.92	17.71
Sodium	6.79	9.31	6.57	5.39
Potassium**	1.16	0.79	1.45	0.73
DOC*	6.69	7.87	5.34	4.72

** Clear water and glacier-fed means significantly different at α=0.05.
* Clear water and glacier-fed means significantly different at α=0.10.

Table 10. Mean analyte concentrations for Denali National Park and Preserve south side clear water and glacier-fed streams and rivers for 1994-1996.

Analyte	Clear water		Glacier-fed	
	Mean	Std. Dev.	Mean	Std. Dev.
	------------------------------- mg L^{-1} -------------------------------			
Chloride**	0.16	0.19	0.10	0.09
Nitrate**	0.10	0.21	0.33	0.31
Sulfate**	30.36	55.96	10.64	11.23
Calcium**	10.67	10.47	7.49	5.32
Magnesium**	6.49	11.27	1.35	1.78
Sodium**	2.27	3.05	0.80	0.30
Potassium	0.67	1.48	0.61	0.32
DOC**	2.56	1.85	1.45	1.28

** Clear water and glacier-fed means significantly different at α=0.05.

Table 11. Correlation matrix for instantaneous discharge (cfs) and ionic constituents of north side clear water streams and rivers in Denali National Park and Preserve, 1994-1996.

	cfs	Cl	NO$_3$	SO$_4$	Ca	Mg	Na	K	DOC
cfs	1.0000								
Cl	0.2157	1.0000							
NO$_3$	-.1454	-.2120	1.0000						
SO$_4$	-.2180	-.2594	0.1978	1.0000					
Ca	-.1564	-.2570	0.2916	0.6443	1.0000				
Mg	-.2069	-.1790	0.1786	0.8977	0.4031	1.0000			
Na	-.1182	-.0359	-.0115	0.1587	-.0213	0.2313	1.0000		
K	-.1232	-.1271	0.1691	0.3630	0.1883	0.3342	0.2948	1.0000	
DOC	0.0064	0.0015	0.0774	0.0704	0.0603	0.1649	0.1369	0.1126	1.0000

Table 12. Correlation matrix for instantaneous discharge (cfs) and ionic constituents of north side glacier-fed streams and rivers in Denali National Park and Preserve, 1994-1996.

	cfs	Cl	NO$_3$	SO$_4$	Ca	Mg	Na	K	DOC
cfs	1.0000								
Cl	0.0993	1.0000							
NO$_3$	0.3183	0.3384	1.0000						
SO$_4$	-.2914	-.2488	0.1904	1.0000					
Ca	-.1605	-.2149	0.2196	0.8658	1.0000				
Mg	-.1820	-.1865	0.3627	0.8976	0.7108	1.0000			
Na	-.2071	0.0718	0.3416	0.4465	0.2031	0.5510	1.0000		
K	-.1875	-.0924	0.0226	0.3571	0.2285	0.3921	0.5741	1.0000	
DOC	0.3010	0.1208	0.6354	0.1708	0.2602	0.2992	0.0409	0.0378	1.0000

Table 13. Correlation matrix for instantaneous discharge (cfs) and ionic constituents of south side clear water streams and rivers in Denali National Park and Preserve, 1994-1996.

	cfs	Cl	NO$_3$	SO$_4$	Ca	Mg	Na	K	DOC
cfs	1.0000								
Cl	0.0112	1.0000							
NO$_3$	0.3523	0.1023	1.0000						
SO$_4$	-.1838	0.1455	0.4532	1.0000					
Ca	-.1786	0.2407	0.2935	0.9259	1.0000				
Mg	-.1970	0.1637	0.4500	0.9806	0.8951	1.0000			
Na	-.2321	0.2093	0.4422	0.9752	0.8881	0.9623	1.0000		
K	0.2271	0.0514	0.3228	0.1777	0.1423	0.1151	0.1021	1.0000	
DOC	-.2765	0.2038	-.0268	0.5188	0.6122	0.4779	0.5545	-.0248	1.0000

Table 14. Correlation matrix for instantaneous discharge (cfs) and ionic constituents of south side glacier-fed streams and rivers in Denali National Park and Preserve, 1994-1996.

	cfs	Cl	NO$_3$	SO$_4$	Ca	Mg	Na	K	DOC
cfs	1.0000								
Cl	0.4675	1.0000							
NO$_3$	0.1490	0.3073	1.0000						
SO$_4$	0.0021	-.0142	-.1328	1.0000					
Ca	-.2771	-.2102	0.0821	0.8431	1.0000				
Mg	0.2567	0.2503	-.0980	0.8335	0.5468	1.0000			
Na	-.2462	0.1071	0.2696	0.6803	0.8068	0.5345	1.0000		
K	0.0993	-.0016	0.4886	0.4195	0.5060	0.2319	0.4870	1.0000	
DOC	-.3769	-.0769	-.0006	0.5809	0.7410	0.2672	0.7386	0.3596	1.0000

correlated strongly to instantaneous flow. However, only those sampling times during which

discharge was measured are included in the correlation analyses. Consequently, the results may

reflect the disproportionate influence of observations recorded from streams and rivers with lower and less turbulent flows or during periods of lower flows. Sampling was more thorough on the north side, and south side glacier-fed streams, in particular, may be under-represented since several of those classified as glacier-fed were influenced by relatively small glaciers.

The most obvious relationship in these matrices (Tables 11-14) is the high correlations between sulfate and calcium and between sulfate and magnesium for all stream types. Although not shown, the results were essentially the same when discharge was excluded from the matrices and when data from all sites were included in the analyses. Sulfate and calcium had the highest ion concentrations in these streams, and magnesium concentrations also were generally substantial (Tables 7-8). These results indicate that calcium sulfate and magnesium sulfate are the dominant ion pairs present in most of the streams and rivers in Denali National Park and Preserve, regardless of their position relative to the Alaska Range and regardless of stream type (either clear or glacier-fed). Sodium also appears to pair with sulfate somewhat strongly in south side glacier-fed streams, although average sodium concentrations were lowest in the south side glacier-fed streams compared to south side clear water streams or either type of stream on the north side (Tables 7-8).

Sulfate, magnesium, and calcium ions apparently are common and dominant ions within much of the geology within the park. In addition, unlike many pristine and non-estuarian surface waters elsewhere in the United States, sodium concentrations commonly were high in many of Denali's

streams and rivers, suggesting that this ion also is associated commonly with geologic formations, possibly marine sediments.

Other statistical analyses, such as cluster analysis, to group individual streams with similar chemical characteristics are possible. However, those analyses require adequate numbers of observations for each stream. Very few observations are available for most of these streams and rivers (Table 1), and the chemistry of many of these streams is quite variable over time and under different flow regimes. Together, these factors make accurate interpretation of many types of statistical analyses difficult at best, and the potential for misinterpretation is high. Consequently, at this time, such analyses for the overall population of streams have not been performed, and they are not recommended unless greater numbers of samples are collected.

There were a few streams within the park and preserve that were selected for more thorough sampling and analysis to investigate possibilities for long-term monitoring. Data from all years were combined to increase the sample size, but still relatively small numbers of observations (compared to intensive monitoring efforts) were available. Thus, conclusions from these site-specific data should be viewed cautiously.

Igloo Creek was sampled at three locations, identified from the headwaters to downstream as Upper Igloo Creek, Igloo Creek at Campground, and the Mouth of Igloo (Fig. 12). At the Upper reach, dominant correlations were between sulfate and magnesium, potassium and chloride, calcium and magnesium, sodium and magnesium, and calcium and sodium (Table 15).

Figure 12. Sampling site at the mouth of Igloo Creek near the confluence with the Teklanika River, July 1994.

Table 15. Correlation matrix for Upper Igloo Creek. All years' data combined.

	cfs	Cl	NO$_3$	SO$_4$	Ca	Mg	Na	K	DOC
cfs	1.0000								
Cl	-.3836	1.0000							
NO$_3$	0.2503	0.4509	1.0000						
SO$_4$	-.2045	0.3107	0.5757	1.0000					
Ca	-.5677	-.2072	-.1503	0.5255	1.0000				
Mg	-.2077	-.0524	0.5179	0.8093	0.6817	1.0000			
Na	-.0095	-.3238	0.4245	0.5878	0.6154	0.9303	1.0000		
K	0.0471	0.7492	0.3339	0.2580	-.3895	-.2801	-.4740	1.0000	
DOC	-.4168	0.2072	0.2785	0.3391	0.2214	0.4811	0.3053	-.2245	1.0000

At the Campground, the concentrations of several of the ions increased compared to the upstream

reach (Table 16). Most notable was sulfate, which increased an average of approximately

20 mg L^{-1}, and sodium which increased from approximately 13 mg L^{-1} to 26 mg L^{-1}. Chloride and

potassium concentrations also showed large percentage increases, although the absolute

concentration of each at either the Upper Igloo or Campground site was low. The number of

moderate and strong correlations present increased at the Campground (Table 17), and calcium

and sodium along with magnesium became associated with sulfate. At the Mouth, analyte

concentrations were similar to those recorded for the Campground site (Table 16); however, the

base cation associations with sulfate were much less pronounced (Table 18). The dominant

cation/anion association was between potassium and chloride.

Table 16. Average concentration data for three Igloo Creek sampling sites.

Analyte	Location		
	Upper	Campground	Mouth
	- mg L^{-1} -		
Chloride	0.32	0.57	0.59
Nitrate	0.70	0.56	0.51
Sulfate	31.73	51.90	50.04
Calcium	29.36	34.66	35.28
Magnesium	9.62	13.49	12.54
Sodium	13.32	26.01	20.12
Potassium	0.85	1.43	1.62
DOC	7.27	8.19	6.01

Table 17. Correlation matrix for Igloo Creek at Campground. All years' data combined.

	cfs	Cl	NO$_3$	SO$_4$	Ca	Mg	Na	K	DOC
cfs	1.0000								
Cl	-.7952	1.0000							
NO$_3$	0.1693	0.0051	1.0000						
SO$_4$	-.5100	0.6560	0.4727	1.0000					
Ca	-.6468	0.6203	-.0453	0.7497	1.0000				
Mg	-.5318	0.4562	0.1818	0.6919	0.7575	1.0000			
Na	-.6359	0.6735	0.1041	0.8370	0.9711	0.8454	1.0000		
K	-.4132	0.8205	0.1889	0.5137	0.4267	0.3083	0.5182	1.0000	
DOC	-.4984	0.2257	-.0365	0.5126	0.3678	0.4237	0.3768	-.2292	1.0000

Table 18. Correlation matrix for Igloo Creek at Mouth. All years' data combined.

	cfs	Cl	NO$_3$	SO$_4$	Ca	Mg	Na	K	DOC
cfs	1.0000								
Cl	-.7734	1.0000							
NO$_3$	0.3214	0.1223	1.0000						
SO$_4$	-.2334	0.3406	0.5798	1.0000					
Ca	-.5918	0.4487	0.0241	0.4566	1.0000				
Mg	-.4115	0.3311	0.1999	0.5265	0.8580	1.0000			
Na	0.1071	0.1512	0.4400	0.2886	0.5470	0.6180	1.0000		
K	-.5784	0.7796	0.2632	0.3826	0.4105	0.2613	-.0377	1.0000	
DOC	0.2762	0.0132	0.3576	0.4400	-.2221	0.0326	0.1049	-.1724	1.0000

Concentration changes and ion association differences suggest that the geology influencing Igloo Creek changes along its length. While sulfate continued to dominate stream chemistry (Table 16), the changes in correlations suggest that the base cation composition in the bedrock and parent material changes. In the upper sections, mineralogy appears to be dominated by magnesium sulfate-containing rocks. At the Campground, calcium, sodium, and magnesium are simultaneously associated with sulfate. At the Mouth, the correlations are blurred but the concentrations remain elevated. This suggests a variety of minerals are present in the bedrock at the mouth and no specific one dominates the geology, though a source of potassium chloride exists.

When data for all Igloo sites and all years are combined (Table 19), the results look similar to that of the middle Igloo site (at the Campground). This depiction is reasonable since it essentially combines all of the relationships evident at each of the individual sites.

Table 19. Correlation matrix for Igloo Creek, all sites and years combined.

	cfs	Cl	NO_3	SO_4	Ca	Mg	Na	K	DOC
cfs	1.0000								
Cl	-.4259	1.0000							
NO_3	0.2087	-.0764	1.0000						
SO_4	-.2950	0.6168	0.3692	1.0000					
Ca	-.5530	0.4587	-.0963	0.6279	1.0000				
Mg	-.3480	0.4805	0.1744	0.7000	0.7665	1.0000			
Na	-.1673	0.5411	0.1519	0.6456	0.7128	0.7818	1.0000		
K	-.3121	0.7954	0.1024	0.5257	0.3777	0.3233	0.3082	1.0000	
DOC	-.2241	0.0750	0.1878	0.3867	0.1230	0.3135	0.2590	-.2012	1.0000

The four Hines Creek sites sampled also were examined individually. The site names from upstream to downstream are Hines Creek Upper, Hines Creek above Rock Creek, Hines Creek at Slump, and Hines Creek at Railroad Trestle (Fig. 13). The number of observations at each site was 7, 7, 6, and 8, respectively; consequently, the reader again is cautioned when interpreting results.

Figure 13. Sampling site on Hines Creek at the railroad trestle, near the confluence with Riley Creek, July 1994.

In this series of reaches, there are a number of interesting results. First, the average concentrations of sulfate, calcium, and magnesium were significantly higher at the Upper site (Table 20) than the downstream sites. In fact, the sulfate concentration at the Upper sampling site, 554 mg L^{-1}, was more than double the concentration at the other three downstream sites. Sulfate, calcium, and magnesium concentrations changed little among the three downstream sampling sites.

Chloride, nitrate, sodium, potassium, and DOC concentrations either changed minimally or increased only slightly between the Hines Creek Upper and the Hines Creek above Rock Creek sites (Table 20).

Table 20. Mean chemical concentrations of stream water at four Hines Creek sampling sites.

Analyte	Location			
	Upper	Above Rock Creek	At Slump	Railroad Trestle
	- - - - - - - - - - - - - - - - - - mg L^{-1} - - - - - - - - - - - - - - - - - -			
Chloride	0.17	0.41	0.34	0.46
Nitrate	0.73	1.13	0.89	1.19
Sulfate	554.20	229.64	159.36	225.88
Calcium	66.36	39.70	38.88	44.58
Magnesium	142.84	60.15	46.62	62.60
Sodium	5.02	9.21	8.58	8.05
Potassium	1.49	1.51	1.37	1.46
DOC	8.31	11.16	11.27	13.54

Unlike the correlations for all the sites combined and those of Igloo Creek, ion concentrations at Hines Creek frequently were correlated strongly with instantaneous discharge; however, the correlations generally were negative, indicating dilution with increased discharge (Table 21-24). There are a lot of different combinations of both strong negative and positive correlations for the individual sampling sites on Hines Creek, but they do not seem to reflect consistent nor predictable changes from upstream to downstream. Much of this erratic behavior simply may reflect random variations resulting from relatively few observations, or the results may be reflecting the unique characteristics of the Hines Creek watershed. Upper Hines Creek is not influenced by any solifluction, while Hines Creek at the slump is affected continuously by solifluction. The lower two sites, although influenced by solifluction, also are subject to dilution by other tributaries.

Despite the limited sample size and changes downstream in the watershed, a few of the Hines Creek correlations remained fairly strong (sulfate and calcium, sulfate and magnesium) and consistent through space and time, suggesting these relationships are real. In both of these associations, the correlation was positive.

Alder Creek and Caribou Creek each were sampled at multiple locations along their length. However, in both cases the number of observations at each site was too small to examine each individually. Consequently, relationships were examined by combining data for all sites and all years for each stream. Even with the combination, the number of observations on Alder Creek was only 11, and 13 on Caribou Creek.

Table 21. Correlation matrix for Upper Hines Creek. All years' data combined.

	cfs	Cl	NO₃	SO₄	Ca	Mg	Na	K	DOC
cfs	1.0000								
Cl	-.3294	1.0000							
NO₃	0.2863	-.1719	1.0000						
SO₄	-.0419	-.8027	-.0099	1.0000					
Ca	-.6348	-.3996	-.1158	0.7597	1.0000				
Mg	0.0116	-.7042	0.3007	0.8694	0.6096	1.0000			
Na	-.5023	0.1654	0.1421	0.2531	0.6509	0.1883	1.0000		
K	0.4575	-.6977	0.6337	0.6635	0.2004	0.8085	0.0152	1.0000	
DOC	0.6686	0.4086	0.1472	-.5604	-.8840	-.3342	-.4657	0.0179	1.0000

Table 22. Correlation matrix for Hines Creek above Rock Creek. All years' data combined.

	cfs	Cl	NO₃	SO₄	Ca	Mg	Na	K	DOC
cfs	1.0000								
Cl	0.3166	1.0000							
NO₃	0.2796	0.9337	1.0000						
SO₄	-.3780	-.3654	-.5559	1.0000					
Ca	-.8380	-.6506	-.6390	0.4610	1.0000				
Mg	-.3309	-.1589	-.3910	0.9589	0.3396	1.0000			
Na	-.9055	-.5759	-.4461	0.3165	0.8276	0.1652	1.0000		
K	0.8442	0.5810	0.6411	-.4869	-.8495	-.3772	-.8341	1.0000	
DOC	-.1017	-.4073	-.2055	-.3410	0.1987	-.3297	0.1834	0.0340	1.0000

Table 23. Correlation matrix for Hines Creek at Slump site. All years' data combined.

	cfs	Cl	NO₃	SO₄	Ca	Mg	Na	K	DOC
cfs	1.0000								
Cl	0.6084	1.0000							
NO₃	-.3288	0.1891	1.0000						
SO₄	-.5917	-.8931	-.4747	1.0000					
Ca	-.8123	-.6503	-.2541	0.8429	1.0000				
Mg	-.5021	-.6133	-.6380	0.8846	0.9063	1.0000			
Na	-.4165	-.0493	0.9590	-.2791	-.1462	-.5273	1.0000		
K	0.9179	0.4544	-.0985	-.5894	-.9170	-.6831	-.1460	1.0000	
DOC	0.5053	-.3105	-.6835	0.2483	-.2017	0.1470	-.5885	0.5155	1.0000

Table 24. Correlation matrix for Hines Creek at Railroad Trestle site. All years' data combined.

	cfs	Cl	NO₃	SO₄	Ca	Mg	Na	K	DOC
cfs	1.0000								
Cl	0.3963	1.0000							
NO₃	-.0391	0.1452	1.0000						
SO₄	-.7936	-.0966	0.5254	1.0000					
Ca	-.8761	-.1795	0.3195	0.8644	1.0000				
Mg	-.6681	-.0203	0.5051	0.8299	0.9153	1.0000			
Na	-.9097	-.5168	0.2208	0.8179	0.9260	0.7861	1.0000		
K	0.3207	0.1101	-.3940	-.5426	-.3143	-.2569	-.4073	1.0000	
DOC	0.3930	0.2100	0.4457	0.0711	-.1182	0.1437	-.1856	0.2700	1.0000

On both creeks, the previously observed correlations between sulfate and base cations were present (Tables 25 and 26). Sulfate was strongly and positively correlated to calcium and magnesium. In addition, on Alder Creek, sulfate was strongly correlated to sodium (Table 25). Potassium was moderately-well correlated to sulfate on Caribou Creek (Table 26).

Table 25. Correlation matrix for Alder Creek. All years' data and all sampling sites combined.

	cfs	Cl	NO$_3$	SO$_4$	Ca	Mg	Na	K	DOC
cfs	1.0000								
Cl	0.5491	1.0000							
NO$_3$	0.4583	0.3427	1.0000						
SO$_4$	-.8012	-.3753	-.7830	1.0000					
Ca	-.8464	-.6890	-.6139	0.8483	1.0000				
Mg	-.7619	-.5912	-.7227	0.8036	0.8487	1.0000			
Na	-.8275	-.2961	-.5310	0.9001	0.7844	0.7230	1.0000		
K	0.5403	0.5168	0.5684	-.6156	-.7869	-.5204	-.4486	1.0000	
DOC	-.4938	-.2443	-.8374	0.8838	0.6806	0.6468	0.7069	-.5095	1.0000

Table 26. Correlation matrix for Caribou Creek. All years data and all sampling sites combined.

	cfs	Cl	NO$_3$	SO$_4$	Ca	Mg	Na	K	DOC
cfs	1.0000								
Cl	-.0113	1.0000							
NO$_3$	0.5315	0.2640	1.0000						
SO$_4$	-.5217	-.5651	-.3870	1.0000					
Ca	-.4659	-.3583	-.1000	0.8423	1.0000				
Mg	-.3435	-.2195	-.0205	0.7536	0.8262	1.0000			
Na	0.1847	-.5022	0.3601	0.3395	0.2805	0.4284	1.0000		
K	-.6270	-.2512	-.0629	0.6670	0.6290	0.5236	0.3274	1.0000	
DOC	0.4159	-.1788	0.0442	-.2685	-.3361	-.0361	0.3859	-.1512	1.0000

Turbidity and Suspended Sediment

Turbidity and suspended sediment were compared between the north and south sides of the park

and preserve by stream type (i.e., glacier-fed and clear) since the sediment loads of each type vary

considerably, even at baseflow. Each year was examined separately (Tables 27-29) and together

for analyses (Table 30). Neither suspended sediment nor turbidity differed significantly between

the north and south side clear water streams (Table 27-30). Note that some of the average

turbidity values given for the clear water streams in Tables 27-30 are higher than might be

expected for streams not influenced by glacial melt. The higher individual turbidity values

subsequently responsible for creating higher averages generally occurred during large

precipitation events. Average suspended sediment and turbidity were significantly greater in

north side glacier-fed streams compared to south side glacier-fed streams for all individual years

(Table 27-29), except for suspended sediment in 1996 (Table 29), and for all years combined

(Table 30). The lack of difference in the 1996 comparison probably was due to the wide variation

in the south side values (Table 29). The minimum suspended sediment levels for both the north

and south sides were similar, < 3 mg L^{-1}, but the maximum values were quite different, 7261 and

5234 mg L^{-1}, respectively, for the north (Upper Thorofare River) and south (Ohio Creek) sides,

respectively. The corresponding turbidity levels for those sediment values were 1616 and 320

NTU.

As with the differences in water chemistry, the significant difference in suspended sediment and

turbidity between the north and south side glacially-influenced streams may reflect differences in

geology. However, as previously mentioned, glacier-fed streams on the south side may be

Table 27. Means and standard deviations of turbidity and suspended sediment for clear water and glacier-fed streams in the north and south sides of Denali National Park and Preserve in 1994.

	North		South	
	Mean	Std. Dev.	Mean	Std. Dev.
CLEAR WATER				
Turbidity (NTU)	3.74	9.89	2.52	3.79
Suspended Sediment (mg L^{-1})	4.37	8.15	2.36	2.39
GLACIER-FED				
Turbidity (NTU) **	362.68	466.17	76.47	85.60
Suspended Sediment (mg L^{-1})**	1392.26	2178.59	98.99	132.98

**North and south side means significantly different at $\alpha=0.05$.

Table 28. Means and standard deviations of turbidity and suspended sediment for clear water and glacier-fed streams in the north and south sides of Denali National Park and Preserve in 1995.

	North		South	
	Mean	Std. Dev.	Mean	Std. Dev.
CLEAR WATER				
Turbidity (NTU)	29.29	144.64	18.39	33.33
Suspended Sediment (mg L^{-1})	35.55	123.54	22.87	40.10
GLACIER-FED				
Turbidity (NTU) **	301.43	494.99	97.56	155.18
Suspended Sediment (mg L^{-1})	518.41	881.59	286.98	915.16

**North and south side means significantly different at $\alpha=0.05$.

Table 29. Means and standard deviations of turbidity and suspended sediment for clear water and glacier-fed streams in the north and south sides of Denali National Park and Preserve in 1996.

	North		South	
	Mean	Std. Dev.	Mean	Std. Dev.
CLEAR WATER				
Turbidity (NTU)	24.73	81.05	17.90	29.28
Suspended Sediment (mg L^{-1})	48.42	195.23	26.02	42.23
GLACIER-FED				
Turbidity (NTU) **	137.57	167.06	54.51	79.51
Suspended Sediment (mg L^{-1})	286.59	389.78	341.36	1187.90

**North and south side means significantly different at $\alpha=0.05$.

Table 30. Means and standard deviations of turbidity and suspended sediment for clear water and glacier-fed streams in the north and south sides of Denali National Park and Preserve in 1994-1996.

	North		South	
	Mean	Std. Dev.	Mean	Std. Dev.
CLEAR WATER				
Turbidity (NTU)	20.65	101.80	14.99	28.61
Suspended Sediment (mg L^{-1})	31.78	138.90	19.84	37.33
GLACIER-FED				
Turbidity (NTU) **	258.19	403.53	79.41	122.17
Suspended Sediment (mg L^{-1})**	670.00	1331.18	266.26	915.97

**North and south side means significantly different at $\alpha=0.05$.

under-represented since several of those sampled were influenced only by relatively small glaciers. In those watersheds, annual precipitation is greater than for any watersheds on the north side, and clear water tributaries dilute the effects that the glaciers have on suspended sediment and turbidity (Figs. 14-16). Several additional factors may affect suspended sediment levels in glacier-fed streams (Gurnell et al. 1996), and these factors should be analyzed for the watershed selected in this baseline inventory.

Suspended sediment and turbidity levels were examined in relation to instantaneous discharge (cfs) using matrix correlation. This analysis included data only for streams and rivers in which discharge could be measured, so relationships in high discharge systems are not discernable in this method.

Flow was correlated only weakly to sediment and turbidity for both glacier-fed and clear water streams and rivers regardless of whether they were located on the north or south side of the park (Table 31). Clear water streams had very small suspended sediment and turbidity ranges which probably caused the low correlation.

The generally strong correlations between suspended sediment and turbidity indicate that suspended sediment can be predicted relatively well from turbidity. Development of a predictive equation is valuable because turbidity is easier, less expensive, and less labor intensive to measure. Turbidity also can be measured in situ. A single mathematical relationship applicable to

Figure 14. Sampling site on Upper Thorofare River near the Sunset Glacier, and an example of a north side stream with high suspended sediment and turbidity levels, July 1994.

Figure 15. Sampling site on Slippery Creek, another north side glacier-fed stream, July 1995.

Figure 16. Sampling site on Hidden Creek, a south side glacier-fed stream with clear water tributaries, June 1994.

Table 31. Correlation matrices for north side clear water streams, north side glacier-fed streams, south side clear water streams, south side glacier-fed streams.

NORTH CLEAR	cfs	Sediment	Turbidity
cfs	1.0000		
Sediment	-.0058	1.0000	
Turbidity	-.0054	0.8311	1.0000
NORTH GLACIER-FED	cfs	Sediment	Turbidity
cfs	1.0000		
Sediment	-.1398	1.0000	
Turbidity	-.1145	0.6988	1.0000
SOUTH CLEAR	cfs	Sediment	Turbidity
cfs	1.0000		
Sediment	0.2042	1.0000	
Turbidity	0.1741	0.9809	1.0000
SOUTH GLACIER-FED	cfs	Sediment	Turbidity
cfs	1.0000		
Sediment	0.2411	1.0000	
Turbidity	0.1537	0.9615	1.0000

the overall park may be adequate for some needs, but a site-specific equation may be necessary for an individual monitoring application. The adequacy of a single-site prediction equation depends upon the sample size from which the equation is developed, as well as the inherent correlation of turbidity and suspended sediment for the site in question.

The overall clear water and glacier-fed stream relationships for the park determined by regression analysis are given in Table 32. These equations include both north and south side data. However, because north and south side glacier-fed stream turbidity and suspended sediment values were significantly different, the glacier-fed stream regressions were run separately for north and south sides (Table 32). The R^2 values for each indicate the strongest prediction would occur for south side clear water streams, and the weakest would occur for the south side glacier-fed streams.

Table 32. Linear regression equation results for predicting suspended sediment (mg L^{-1}) from turbidity (NTU). Equations are in the form y=mx+b, where b is the intercept, m is the slope, x is turbidity, and y is suspended sediment.

	Intercept	Slope	R^2	Range of x values	
				Max.	Min.
All glacier-fed streams	-25.948	2.907	0.64	2048	0.4
All clear water streams	7.081	1.131	0.70	1536	0.1
North side glacier-fed	-35.424	2.752	0.70	2048	0.7
South side glacier-fed	-194.170	5.798	0.60	760	0.4
North side clear	8.038	1.128	0.70	1536	0.1
South side clear	0.651	1.280	0.96	140	0.1

The specific relationship between turbidity and suspended sediment also was examined for the four streams used earlier in individual analyses: Igloo Creek, Hines Creek, Alder Creek, and Caribou Creek. The slope and intercept coefficients for each equation along with the R^2 value for each stream are given in Table 33. The range of turbidity values from which each equation in

Table 33. Linear regression equation results for predicting suspended sediment (mg L^{-1}) from turbidity (NTU) for specific streams. Equations are in the form y=mx+b, where b is the intercept, m is the slope, x is turbidity, and y is suspended sediment.

	Intercept	Slope	R^2	Range of x values
Alder Creek	-3.518	1.530	0.94	0.4 - 284
Caribou Creek	-0.350	3.733	0.97	0.2 - 11.0
Hines Creek	67.123	1.027	0.62	0.2 - 1536
Igloo Creek	0.378	1.288	0.90	0.1 - 15.6

Tables 32-33 was calculated is provided, because extrapolation beyond these values is risky. Generally, turbidity-suspended sediment relationships tend to become more nonlinear or at least deviate from the specified linear relationship as the turbidity values move farther outside the ranges from which they were defined.

As might be expected, the individual stream equations generally resulted in more accurate predictions (Table 33) than the overall predictions (Table 32), based upon the R^2 values. The wide range of streams represented in each classification in Table 32 makes accurate prediction more difficult. Data used in developing these regression relationships were graphed to determine the fit of the line to the data. In several cases, only one or two points at the high end of turbidity or suspended sediment seemed to negatively affect the prediction equation. These may be due to anomalies or individual sites that do not fit the trend. Additional data at high-end values would help clarify the relationship or enable a second linear or curvilinear relationship to be developed.

Geology, Stream Chemistry, and Sediment

Chemical and turbidity/suspended sediment results reflect significant geologic differences throughout the park and preserve, particularly between the north and south sides. While demonstrating cause and effect between geology and water chemistry is not possible with the available data set, some geologic differences are discussed here.

On the south side, sampled streams traverse two general types of stratigraphy: shelf to upper slope marine sedimentary rocks and felsic granitic rocks (Table 34). Granitic terrains on the south side are relatively inert and resistant to weathering. Sediment and dissolved ion concentrations in these waters should, therefore, generally be lower than those observed in waters from the sedimentary formations where weathering occurs more rapidly.

Table 34. South side streams in the two geologic types.

Marine Sedimentary		Granitic	
Alder Creek Upper	Morris Creek	Cascade Creek	Hidden Creek
Alder Creek Mouth	Ohio Creek	Cloud Creek	Slide Creek
Bear Creek	Whistler Creek	Cripple Creek	Snowslide Creek
Kichatna River	Wildhorse Creek	Crystal Creek	

Mean ionic concentrations and turbidity and suspended sediment levels for streams in marine and granitic formations were compared using t-tests to determine if significant differences exist (Table 35). Results are given for the three years individually (Tables 35a-c) and for the three years combined (Table 35d). Alkalinity, calcium, magnesium, sodium, and sulfate concentrations were

Table 35a. Mean, minimum, and maximum concentrations for streams and rivers traversing marine sedimentary and granitic rock formations on the south side in 1994.

Analyte	Granitic			Marine Sedimentary		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Alkalinity **	10.24	3.50	16.13	24.62	16.34	40.29
Chloride	0.13	0.08	0.23	0.13	0.10	0.16
Nitrate	0.20	0.00	0.66	0.18	0.00	0.66
Sulfate *	3.39	1.52	6.52	16.74	0.88	94.15
Calcium **	3.64	1.20	6.53	10.33	5.29	29.20
Magnesium* *	0.49	0.17	1.11	2.58	0.66	12.30
Sodium **	0.69	0.39	0.91	1.03	0.70	1.97
Potassium	0.51	0.19	0.94	0.52	0.09	1.09
DOC	1.74	0.69	3.91	2.78	0.63	8.32

** Granitic and marine sedimentary means significantly different at $\alpha=0.05$.
* Granitic and marine sedimentary means significantly different at $\alpha=0.10$.

Table 35b. Mean, minimum, and maximum concentrations for streams and rivers traversing marine sedimentary and granitic rock formations on the south side in 1995.

Analyte	Granitic			Marine Sedimentary		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Alkalinity **	8.25	2.35	16.99	23.42	8.90	39.19
Chloride	0.07	0.00	0.24	0.08	0.00	0.32
Nitrate	0.12	0.00	0.66	0.19	0.00	1.20
Sulfate **	2.62	0.76	7.41	11.07	1.75	40.05
Calcium **	2.78	0.70	7.59	9.26	4.07	19.42
Magnesium **	0.52	0.09	1.98	1.91	0.56	5.48
Sodium **	0.60	0.26	1.04	0.98	0.49	1.63
Potassium	0.43	0.24	0.97	1.13	0.04	12.00
DOC **	0.95	0.58	1.81	1.62	0.68	3.27

** Granitic and marine sedimentary means significantly different at $\alpha=0.05$.

Table 35c. Mean, minimum, and maximum concentrations for streams and rivers traversing marine sedimentary and granitic rock formations on the south side in 1996.

Analyte	Granitic			Marine Sedimentary		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Alkalinity **	8.54	2.67	15.19	26.24	20.09	38.76
Chloride **	0.15	0.00	0.26	0.07	0.00	0.23
Nitrate	0.29	0.00	0.71	0.22	0.00	0.97
Sulfate **	2.74	1.38	4.57	17.78	3.25	73.64
Calcium **	3.38	1.24	5.69	12.91	6.80	28.40
Magnesium **	0.51	0.11	1.03	3.05	0.69	12.68
Sodium **	0.70	0.32	1.14	1.08	0.76	1.65
Potassium	0.49	0.25	0.84	0.57	0.08	1.17
DOC **	1.11	0.59	1.80	1.87	0.77	3.35

** Granitic and marine sedimentary means significantly different at α=0.05.

Table 35d. Mean, minimum, and maximum concentrations for streams and rivers traversing marine sedimentary and granitic rock formations on the south side in 1994-1996.

Analyte	Granitic			Marine Sedimentary		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Alkalinity **	8.78	2.35	16.99	24.57	8.90	40.29
Chloride	0.11	0.00	0.26	0.09	0.00	0.32
Nitrate	0.19	0.00	0.71	0.20	0.00	1.20
Sulfate **	2.83	0.76	7.41	14.77	0.88	94.15
Calcium **	3.14	0.70	7.59	10.65	4.07	29.20
Magnesium **	0.51	0.09	1.98	2.45	0.56	12.68
Sodium **	0.65	0.26	1.14	1.02	0.49	1.97
Potassium	0.47	0.19	0.97	0.78	0.04	12.00
DOC **	1.17	0.58	3.91	2.05	0.63	8.32

** Granitic and marine sedimentary means significantly different at α=0.05.

statistically greater in streams in watersheds dominated by marine sedimentary rocks for individual years and for all years combined.

When the analyses were separated by clear water and glacier-fed streams, somewhat different patterns existed (Tables 36-37). The only consistent year-to-year statistical differences for clear water streams exist for alkalinity and sodium (Table 36). Both ions had higher concentrations in marine sediment-derived streams. Concentration differences for the glacier-fed streams were much more similar to those of all the streams combined. Alkalinity, sulfate, calcium, magnesium, sodium, and potassium concentrations were all significantly higher in the marine sediment-derived streams (Table 37).

Suspended sediment and turbidity levels were not significantly different between the two geologic types for any individual year (Table 38a-c), even though the values for both analytes were higher in all cases from the marine sedimentary geology. When the three years of data were combined, significant differences became apparent (Table 38d). The greater number of observations in the combined data set permitted more sensitivity in the statistical comparisons.

Additional separation into glacier-fed and clear water systems had little effect on the statistical comparisons (Tables 39-40). The most notable difference was that the mean turbidity and suspended sediment levels for the marine sedimentary clear water streams were lower than the granitic clear water streams, though not statistically lower. Thus, mineral weathering appears to be more influenced by geology than does sediment release.

Table 36a. Mean, minimum, and maximum concentrations for clear water streams and rivers traversing marine sedimentary and granitic rock formations on the south side in 1994.

Analyte	Granitic			Marine Sedimentary		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Alkalinity **	11.50	6.29	16.13	27.30	20.47	40.29
Chloride	0.13	0.08	0.23	0.13	0.11	0.15
Nitrate	0.13	0.00	0.66	0.03	0.00	0.18
Sulfate	4.57	2.58	6.52	16.98	3.42	94.15
Calcium *	4.21	2.10	6.53	10.54	5.29	29.20
Magnesium	0.58	0.31	1.11	3.31	1.65	12.30
Sodium **	0.72	0.51	0.91	1.12	0.85	1.97
Potassium **	0.60	0.40	0.94	0.25	0.09	0.55
DOC	2.21	1.50	3.91	2.77	0.91	7.01

** Granitic and marine sedimentary means significantly different at $\alpha=0.05$.
* Granitic and marine sedimentary means significantly different at $\alpha=0.10$.

Table 36b. Mean, minimum, and maximum concentrations for clear water streams and rivers traversing marine sedimentary and granitic rock formations on the south side in 1995.

Analyte	Granitic			Marine Sedimentary		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Alkalinity **	10.87	6.77	16.99	25.18	14.04	34.05
Chloride	0.07	0.00	0.24	0.08	0.00	0.20
Nitrate	0.08	0.00	0.66	0.06	0.00	0.44
Sulfate	4.03	2.37	7.41	8.29	1.75	40.05
Calcium **	3.83	1.13	7.59	8.10	4.07	12.60
Magnesium**	0.81	0.35	1.98	2.03	0.97	3.47
Sodium **	0.71	0.51	1.02	1.05	0.58	1.30
Potassium	0.59	0.29	0.97	1.43	0.04	12.00
DOC **	1.08	0.73	1.81	1.97	1.06	3.27

** Granitic and marine sedimentary means significantly different at $\alpha=0.05$.

Table 36c. Mean, minimum, and maximum concentrations for clear water streams and rivers traversing marine sedimentary and granitic rock formations on the south side in 1996.

Analyte	Granitic			Marine Sedimentary		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Alkalinity **	10.31	7.38	13.20	26.21	20.78	38.76
Chloride	0.17	0.15	0.21	0.07	0.00	0.19
Nitrate	0.23	0.00	0.71	0.00	0.00	0.00
Sulfate	3.75	3.08	4.57	17.64	3.25	73.64
Calcium	4.17	2.38	5.69	11.80	6.80	28.40
Magnesium	0.68	0.39	1.03	3.98	1.67	12.68
Sodium **	0.78	0.70	0.87	1.14	0.93	1.65
Potassium **	0.64	0.43	0.84	0.20	0.08	0.44
DOC **	1.24	0.89	1.80	2.16	1.55	3.35

** Granitic and marine sedimentary means significantly different at $\alpha=0.05$.

Table 36d. Mean, minimum, and maximum concentrations for clear water streams and rivers traversing marine sedimentary and granitic rock formations on the south side in 1994-1996.

Analyte	Granitic			Marine Sedimentary		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Alkalinity **	10.89	6.29	16.99	26.07	14.04	40.29
Chloride	0.11	0.00	0.24	0.09	0.00	0.20
Nitrate	0.13	0.00	0.71	0.04	0.00	0.44
Sulfate	4.10	2.37	7.41	13.42	1.75	94.15
Calcium **	4.03	1.13	7.59	9.79	4.07	29.20
Magnesium **	0.71	0.31	1.98	2.92	0.97	12.68
Sodium **	0.73	0.51	1.02	1.09	0.58	1.97
Potassium	0.61	0.29	0.97	0.74	0.04	12.00
DOC **	1.43	0.73	3.91	2.28	0.91	7.01

** Granitic and marine sedimentary means significantly different at $\alpha=0.05$.

Table 37a. Mean, minimum, and maximum concentrations for glacier-fed streams and rivers traversing marine sedimentary and granitic rock formations on the south side in 1994.

Analyte	Granitic Mean	Minimum	Maximum	Marine Sedimentary Mean	Minimum	Maximum
Alkalinity **	8.36	3.50	11.55	22.32	16.34	35.93
Chloride	0.13	0.09	0.16	0.12	0.10	0.16
Nitrate	0.32	0.27	0.40	0.33	0.04	0.66
Sulfate **	1.62	1.52	1.77	16.49	0.88	38.66
Calcium **	2.78	1.20	3.97	10.12	6.78	14.10
Magnesium **	0.35	0.17	0.55	1.85	0.66	4.58
Sodium **	0.64	0.39	0.81	0.95	0.70	1.30
Potassium **	0.38	0.19	0.48	0.79	0.45	1.09
DOC	1.02	0.69	1.56	2.79	0.63	8.32

** Granitic and marine sedimentary means significantly different at $\alpha=0.05$.

Table 37b. Mean, minimum, and maximum concentrations for glacier-fed streams and rivers traversing marine sedimentary and granitic rock formations on the south side in 1995.

Analyte	Granitic Mean	Minimum	Maximum	Marine Sedimentary Mean	Minimum	Maximum
Alkalinity **	6.07	2.35	15.05	21.67	8.90	39.19
Chloride	0.07	0.00	0.20	0.07	0.00	0.32
Nitrate	0.15	0.00	0.66	0.32	0.00	1.20
Sulfate **	1.44	0.76	4.06	13.85	4.00	33.67
Calcium **	1.91	0.70	4.35	10.42	5.86	19.42
Magnesium **	0.28	0.09	0.74	1.78	0.56	5.48
Sodium **	0.50	0.26	1.04	0.91	0.49	1.63
Potassium **	0.30	0.24	0.46	0.82	0.37	1.74
DOC *	0.83	0.58	1.50	1.28	0.68	2.46

** Granitic and marine sedimentary means significantly different at $\alpha=0.05$.

* Granitic and marine sedimentary means significantly different at $\alpha=0.10$.

Table 37c. Mean, minimum, and maximum concentrations for glacier-fed streams and rivers traversing marine sedimentary and granitic rock formations on the south side in 1996.

Analyte	Granitic			Marine Sedimentary		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Alkalinity **	6.78	2.67	15.19	26.27	20.09	38.21
Chloride	0.13	0.00	0.26	0.07	0.00	0.23
Nitrate	0.35	0.00	0.66	0.36	0.00	0.97
Sulfate **	1.73	1.38	2.06	17.87	6.39	47.19
Calcium **	2.59	1.24	4.68	13.61	8.48	26.24
Magnesium *	0.34	0.11	0.79	2.47	0.69	9.22
Sodium **	0.63	0.32	1.14	1.04	0.76	1.47
Potassium **	0.35	0.25	0.43	0.81	0.36	1.17
DOC **	0.99	0.59	1.65	1.69	0.77	2.07

** Granitic and marine sedimentary means significantly different at $\alpha=0.05$.
* Granitic and marine sedimentary means significantly different at $\alpha=0.10$.

Table 37d. Mean, minimum, and maximum concentrations for glacier-fed streams and rivers traversing marine sedimentary and granitic rock formations on the south side in 1994-1996.

Analyte	Granitic			Marine Sedimentary		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Alkalinity **	6.68	2.35	15.19	23.27	8.90	39.19
Chloride	0.10	0.00	0.26	0.09	0.00	0.32
Nitrate	0.24	0.00	0.66	0.34	0.00	1.19
Sulfate **	1.55	0.76	4.06	15.96	0.88	47.19
Calcium **	2.25	0.70	4.68	11.39	5.86	26.24
Magnesium **	0.31	0.09	0.79	2.03	0.56	9.22
Sodium **	0.56	0.26	1.14	0.96	0.49	1.63
Potassium **	0.33	0.19	0.48	0.81	0.36	1.74
DOC **	0.91	0.58	1.65	1.86	0.63	8.32

** Granitic and marine sedimentary means significantly different at $\alpha=0.05$.

Table 38a. Mean, minimum, and maximum turbidity and suspended sediment for streams and rivers traversing marine sedimentary and granitic rock formations on the south side in 1994.

Parameter	Granitic			Marine Sedimentary		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Turbidity	26.28	0.30	129.00	48.66	0.10	300.00
Sediment	24.77	0.36	107.57	68.83	0.00	465.90

Table 38b. Mean, minimum, and maximum turbidity and suspended sediment for streams and rivers traversing marine sedimentary and granitic rock formations on the south side in 1995.

Parameter	Granitic			Marine Sedimentary		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Turbidity	24.52	0.30	84.00	101.28	0.30	760.00
Sediment	37.39	0.00	128.87	364.10	0.00	4904.82

Table 38c. Mean, minimum, and maximum turbidity and suspended sediment for streams and rivers traversing marine sedimentary and granitic rock formations on the south side in 1996.

Parameter	Granitic			Marine Sedimentary		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Turbidity	16.13	0.20	79.00	55.16	0.30	320.00
Sediment	30.97	0.00	137.45	453.78	0.00	5233.97

Table 38d. Mean, minimum, and maximum turbidity and suspended sediment for streams and rivers traversing marine sedimentary and granitic rock formations on the south side in 1994-1996.

Parameter	Granitic			Marine Sedimentary		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Turbidity **	22.63	0.20	129.00	71.59	0.10	760.00
Sediment *	32.77	0.00	137.45	298.15	0.00	5233.97

** Granitic and marine sedimentary means significantly different at $\alpha=0.05$.

* Granitic and marine sedimentary means significantly different at $\alpha=0.10$.

Table 39a. Mean, minimum, and maximum turbidity and suspended sediment for clear water streams and rivers traversing marine sedimentary and granitic rock formations on the south side in 1994.

	Granitic			Marine Sedimentary		
Parameter	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Turbidity	4.63	0.30	12.70	0.70	0.10	1.90
Sediment	3.55	0.36	7.40	1.34	0.00	3.77

Table 39b. Mean, minimum, and maximum turbidity and suspended sediment for clear water streams and rivers traversing marine sedimentary and granitic rock formations on the south side in 1995.

	Granitic			Marine Sedimentary		
Parameter	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Turbidity	13.09	0.30	71.00	2.61	0.30	10.70
Sediment	19.56	0.00	91.97	3.34	0.00	15.33

Table 39c. Mean, minimum, and maximum turbidity and suspended sediment for clear water streams and rivers traversing marine sedimentary and granitic rock formations on the south side in 1996.

	Granitic			Marine Sedimentary		
Parameter	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Turbidity	4.33	0.20	19.00	1.94	0.30	7.70
Sediment	7.45	0.00	28.70	2.66	0.00	10.39

Table 39d. Mean, minimum, and maximum turbidity and suspended sediment for clear water streams and rivers traversing marine sedimentary and granitic rock formations on the south side in 1994-1996.

	Granitic			Marine Sedimentary		
Parameter	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Turbidity *	8.40	0.20	71.00	1.81	0.10	10.70
Sediment *	11.89	0.00	91.97	2.51	0.00	15.33

* Granitic and marine sedimentary means significantly different at $\alpha=0.10$.

Table 40a. Mean, minimum, and maximum turbidity and suspended sediment for glacier-fed streams and rivers traversing marine sedimentary and granitic rock formations on the south side in 1994.

Parameter	Granitic			Marine Sedimentary		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Turbidity	58.75	7.00	129.00	96.63	0.40	300.00
Sediment	56.60	8.57	107.57	136.32	1.11	465.90

Table 40b. Mean, minimum, and maximum turbidity and suspended sediment for glacier-fed streams and rivers traversing marine sedimentary and granitic rock formations on the south side in 1995.

Parameter	Granitic			Marine Sedimentary		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Turbidity *	34.05	2.70	84.00	199.94	0.50	760.00
Sediment	56.60	8.57	107.57	136.32	1.11	465.90

* Granitic and marine sedimentary means significantly different at $\alpha=0.10$.

Table 40c. Mean, minimum, and maximum turbidity and suspended sediment for glacier-fed streams and rivers traversing marine sedimentary and granitic rock formations on the south side in 1996.

Parameter	Granitic			Marine Sedimentary		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Turbidity	27.92	6.00	79.00	88.43	0.40	320.00
Sediment	54.50	3.79	137.45	735.74	1.11	5233.97

Table 40d. Mean, minimum, and maximum turbidity and suspended sediment for glacier-fed streams and rivers traversing marine sedimentary and granitic rock formations on the south side in 1994-1996.

Parameter	Granitic			Marine Sedimentary		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Turbidity **	36.87	2.70	129.00	132.64	0.40	760.00
Sediment *	53.66	3.61	137.45	556.82	0.00	5233.97

** Granitic and marine sedimentary means significantly different at $\alpha=0.05$.

* Granitic and marine sedimentary means significantly different at $\alpha=0.10$.

Comparison of Placer Mined Streams with Undisturbed Streams

Streams affected by mining activities that were sampled during the 1994-1996 field seasons included Caribou Creek (lower and middle sampling sites), Eureka Creek, Friday Creek, Glacier Creek (middle and upper sampling sites), Glen Creek (lower and middle sampling sites), Moose Creek (lower and at bridge sampling sites), and North Fork (lower sampling site). Undisturbed or control streams sampled in the Kantishna Hills area included Caribou Creek (upper sampling site), Jumbo Creek, Moose Creek (upper sampling site), North Fork (middle sampling site), Rainy Creek, and Rock Creek (upper and lower sampling sites) (Figs. 17-18).

Average ion concentrations were generally higher for the mined streams than for the undisturbed streams (Table 41). However, the differences were statistically significant ($\alpha=0.10$) from year to year only for sulfate, calcium, and magnesium. The elevated concentrations may be due to past mining disturbances, or they may be an artifact of geologic differences among streams that either were selected or excluded from mining ventures.

Average turbidity and suspended sediment levels were extremely low in almost all cases, and they were very similar for both mined and undisturbed streams (Table 42). The minimum values for both types of streams were identical or almost identical for turbidity and suspended sediment. The maximum values were greater for the undisturbed streams. Again, this may be due to past activities or simply that areas selected for mining would possess geologic and edaphic features more conducive to weathering and erosion than areas that would have been excluded from mining.

Figure 17. Caribou Creek, upper sampling site, July 1995.

Figure 18. Rock Creek (Kantishna), upper sampling site, June 1994.

Table 41a. Mean, minimum, and maximum concentrations for mined and undisturbed streams in Kantishna Hills in 1994.

Analyte	Mined			Undisturbed		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Alkalinity *	102.39	46.00	175.58	80.25	36.24	124.75
Chloride	0.66	0.16	2.42	0.39	0.14	1.85
Nitrate	0.99	0.04	1.95	0.78	0.09	1.46
Sulfate *	133.40	15.60	239.55	80.34	3.24	316.40
Calcium *	53.27	18.20	95.30	39.21	11.40	103.50
Magnesium *	15.94	3.50	34.20	10.23	2.24	34.25
Sodium	1.98	1.13	4.21	1.90	0.94	4.57
Potassium	1.42	0.42	5.20	1.09	0.43	2.98
DOC	2.95	1.21	9.48	2.79	1.28	6.08

* Mined and undisturbed means significantly different at $\alpha=0.10$.

Table 41b. Mean, minimum, and maximum concentrations for mined and undisturbed streams in Kantishna Hills in 1995.

Analyte	Mined			Undisturbed		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Alkalinity	101.19	49.25	149.32	85.21	67.76	111.96
Chloride	0.66	0.19	1.95	0.73	0.24	2.31
Nitrate	1.26	0.44	3.45	0.94	0.00	1.95
Sulfate *	131.80	26.24	254.40	65.47	3.28	172.30
Calcium *	59.13	19.42	101.67	42.01	18.30	75.76
Magnesium *	18.57	0.12	35.63	9.73	0.36	26.34
Sodium	1.75	0.80	5.51	2.05	0.50	4.57
Potassium	0.96	0.41	1.85	0.77	0.38	1.34
DOC	6.06	1.56	11.71	5.57	1.31	10.04

* Mined and undisturbed means significantly different at $\alpha=0.10$.

Table 41c. Mean, minimum, and maximum concentrations for mined and undisturbed streams in Kantishna Hills in 1996.

Analyte	Mined			Undisturbed		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Alkalinity *	92.33	49.73	151.46	76.06	57.47	103.18
Chloride	0.59	0.11	2.59	0.73	0.00	4.45
Nitrate	1.16	0.58	2.39	0.91	0.00	1.68
Sulfate *	122.25	33.99	243.20	73.87	2.57	222.80
Calcium *	58.08	25.16	99.16	42.82	21.92	73.54
Magnesium *	17.15	5.82	30.83	10.44	2.94	25.46
Sodium	1.62	0.68	3.72	1.68	0.14	5.75
Potassium	0.94	0.39	1.77	0.87	0.40	1.41
DOC	5.81	1.39	8.78	5.36	3.67	9.73

* Mined and undisturbed means significantly different at $\alpha=0.10$.

Table 41d. Mean, minimum, and maximum concentrations for mined and undisturbed streams in Kantishna Hills in 1994-1996.

Analyte	Mined			Undisturbed		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Alkalinity *	99.09	46.00	175.58	80.27	36.24	124.75
Chloride	0.64	0.11	2.59	0.59	0.00	4.45
Nitrate *	1.13	0.04	3.45	0.86	0.00	1.95
Sulfate *	129.50	15.60	254.50	74.23	2.57	316.40
Calcium *	56.74	18.20	101.67	41.12	11.40	103.50
Magnesium *	17.23	0.12	35.63	10.16	0.36	34.25
Sodium	1.79	0.68	5.51	1.87	0.14	5.75
Potassium	1.12	0.39	5.20	0.93	0.38	2.98
DOC	4.88	1.21	11.71	4.37	1.28	10.04

* Mined and undisturbed means significantly different at $\alpha=0.10$.

Table 42a. Mean, minimum, and maximum suspended sediment and turbidity values for mined and undisturbed streams in Kantishna Hills in 1994.

Parameter	Mined			Undisturbed		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Sediment	2.04	0.00	8.58	1.91	0.00	23.87
Turbidity	0.87	0.10	3.50	1.02	0.10	12.90

Table 42b. Mean, minimum, and maximum suspended sediment and turbidity values for mined and undisturbed streams in Kantishna Hills in 1995.

Parameter	Mined			Undisturbed		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Sediment	13.22	0.00	272.92	14.84	0.00	161.22
Turbidity	5.46	0.20	110.00	7.95	0.30	85.00

Table 42c. Mean, minimum, and maximum suspended sediment and turbidity values for mined and undisturbed streams in Kantishna Hills in 1996.

Parameter	Mined			Undisturbed		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Sediment	4.88	0.00	39.95	4.89	0.00	29.14
Turbidity	1.49	0.20	11.00	1.75	0.20	7.60

Table 42d. Mean, minimum, and maximum suspended sediment and turbidity values for mined and undisturbed streams in Kantishna Hills in 1994-1996.

Parameter	Mined			Undisturbed		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Sediment	6.84	0.00	272.92	6.38	0.00	161.22
Turbidity	2.69	0.10	110.00	3.14	0.10	85.00

The concentration and sediment data suggest that the long-term effects of mining disturbance anticipated in studies conducted during the early 1980s did not develop. While the current inventory did not include analyses of trace or heavy metals, which still could be relatively high in some Kantishna streams, high pH values observed during 1994-1996 suggest that dissolved trace and heavy metals are not present in high concentrations in the sampled streams. Some turbidity data are available from studies conducted in 1979, 1982, and 1983. Although the sample numbers and locations are limited, turbidity levels observed on mined streams in these previous years were considerably greater than those observed on the same streams during 1994-1996. Mining-related activities have been minimal since 1985 compared to the early 1980s, and substantial recovery, such as regrowth of vegetation, is occurring in several of the Kantishna watersheds. These changes probably are responsible for most of the turbidity change. Future monitoring of mined streams in the Kantishna Hills is recommended to document the extent to which recovery continues and to provide data for restoration projects.

Other watersheds outside Kantishna Hills have been affected by mining and mining-related activities in the past, including Long Creek, Camp Creek, Costello Creek, Slippery Creek (east and west branches), Colorado Creek (at mouth), and Bear Creek. Water chemistry, turbidity, and suspended sediment results from these streams were much like the results from similar undisturbed watersheds. However, more sampling and analysis of additional parameters, such as trace and heavy metals, may be useful in watersheds potentially subject to future disturbances, such as Long Creek and Bear Creek.

RECOMMENDATIONS FOR LONG-TERM MONITORING

One of the objectives in gathering baseline data for streams throughout Denali National Park and Preserve was to identify potential sites for inclusion in the Long-Term Ecological Monitoring Program (LTEM) for the park. As with any monitoring program, both short-term and long-term objectives will determine site selection. Since objectives and needs change over time, flexibility must be built into the monitoring program, with the recognition that objectives may change, and monitoring priorities will be adjusted accordingly. The following recommendations are made based upon the park's current needs and objectives for long-term monitoring.

1. One or more south side streams should be included in the park's long-term monitoring efforts. South side streams have lower alkalinity levels and, therefore, lower buffering capacity than those on the north side. Lower ion concentrations also were observed on south side streams. As a result, these streams will be the most sensitive to natural or human-induced disturbances. Watersheds, such as Bear Creek, Wildhorse Creek, and Upper Alder Creek, are probably some of the most likely to demonstrate changes.

2. One or more streams within the designated wilderness should be included in the long-term monitoring program. These watersheds are likely to be affected the least by direct human-induced changes, and they can be used as a measure of background change that also might affect other sites. Background changes could include natural processes, such as vegetational succession or

geologic events, indirect human-induced changes, such as air pollution on a global or regional scale, or a combination, such as global climate change.

3. Long Creek, in Denali State Park (Fig. 19), is a potential candidate for long-term monitoring because of proposed development in the area. Turbidity and suspended sediment data are especially important given the proposed construction projects. More data collection and follow-up monitoring should be done before any land disturbance occurs to develop an adequate data base from which disturbance effects can be compared statistically. Monitoring should include in situ turbidity measurements (e.g., as done with the Hydrolab) for periods of at least 48 hours in a variety of weather conditions and at different discharge levels. An automatic sampler could be used in conjunction with the Hydrolab unit to collect samples at the same time the Hydrolab takes readings. Suspended sediment should be determined from the samples collected. Sufficient data should be collected to develop a regression relationship predicting suspended sediment from turbidity.

Turbidity then should be measured during the construction period and during inactive periods within the construction phase, such as during evenings. Turbidity also should be measured in years subsequent to construction disturbance. Measuring during active and inactive construction periods over both the short- and long-term will allow recovery to be monitored and described. Short-term recovery may occur during inactive periods, but total recovery to pre-construction levels may take significantly longer. If the turbidity levels found during pre-construction periods are exceeded significantly during construction, suspended sediment should be added to the

Figure 19. Sampling site on Long Creek in Denali State Park, June 1995.

construction phase monitoring, because it is likely that the turbidity/suspended sediment relationships developed during pre-construction will not apply to these high levels.

In conjunction with Long Creek monitoring, baseline water chemistry should be determined from grab samples during the Hydrolab monitoring periods. These baseline samples should be taken from Long Creek, Wildhorse Creek, and Bear Creek. The latter two are comparable watersheds that would not be disturbed by the proposed development near Long Creek.

4. Moose Creek should be monitored pending potential development of an access road along it to reach privately-owned land on Spruce Creek. This monitoring would be similar to that for Long Creek, with additional turbidity and suspended sediment measurement during and immediately after vehicles ford the stream. Turbidity measurements upstream and downstream from each ford would provide a way to make same-time comparisons of fording effects. Hydrocarbon analyses of stream water also should be monitored in conjunction with the increased number of vehicles fording the stream to more thoroughly evaluate these impacts.

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APPENDIX A: SAMPLE GRAPHS FROM HYDROLAB DATA

Sanctuary River
July 10-11, 1996

Igloo Creek at Campground
July 16-17, 1996

** Data not recorded

Thorofare River
July 18-19, 1996

—o— Temperature
—♦— Turbidity

** Data not recorded

Alder Creek at Mouth
August 12-13, 1996

Upper Hines Creek
September 3-4, 1996

Hines Creek at Railroad Trestle
September 12-13, 1996

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
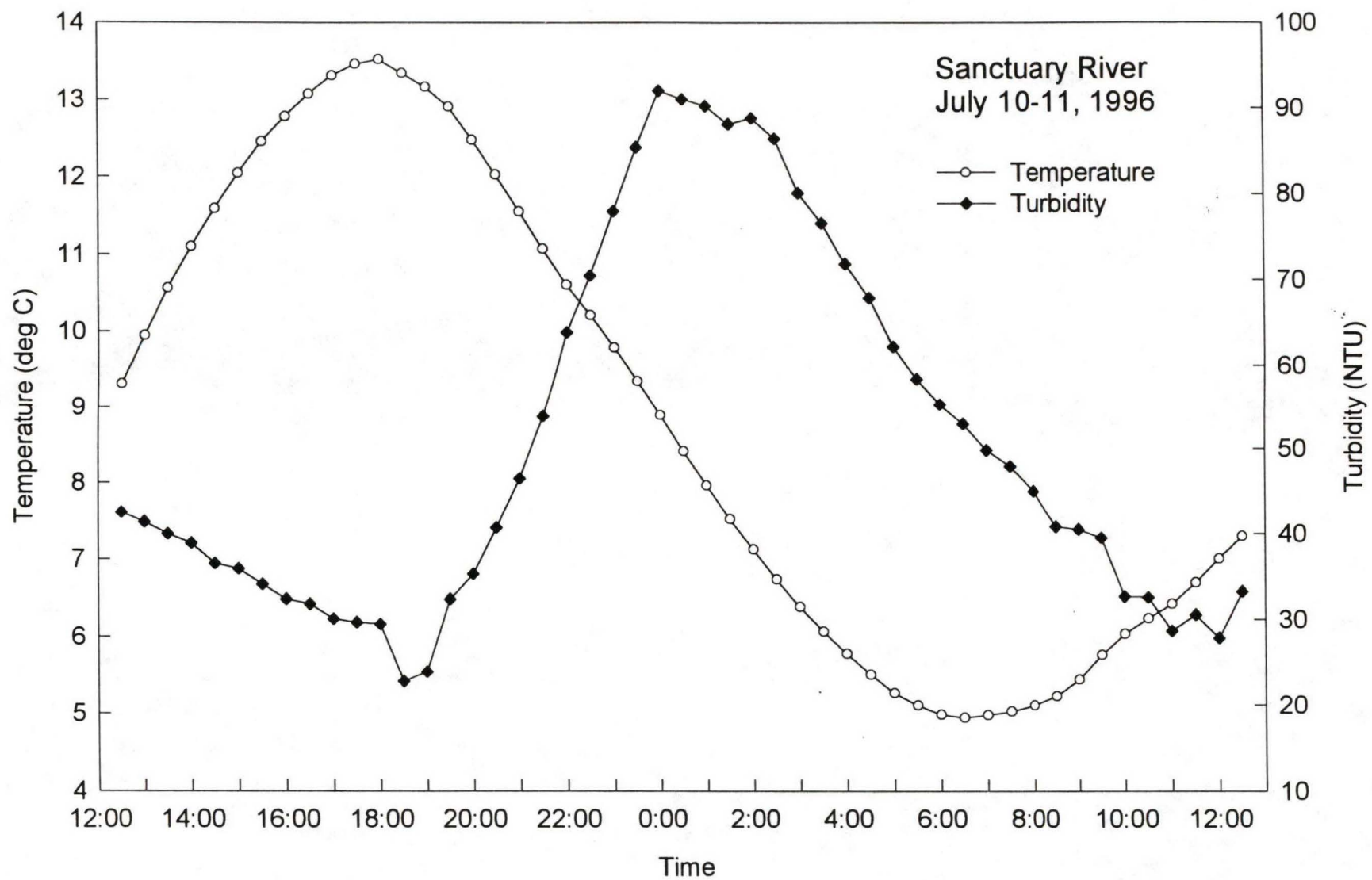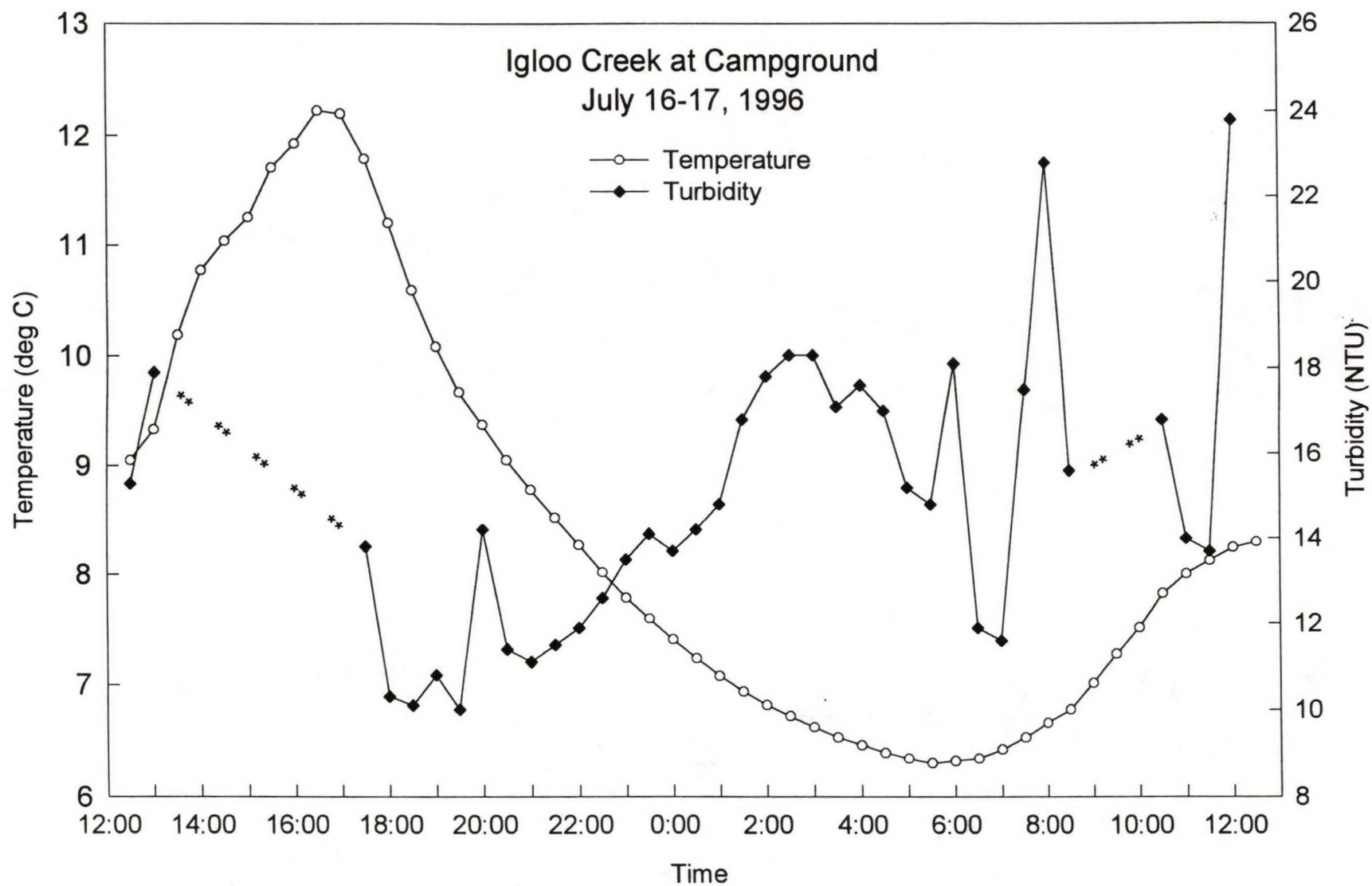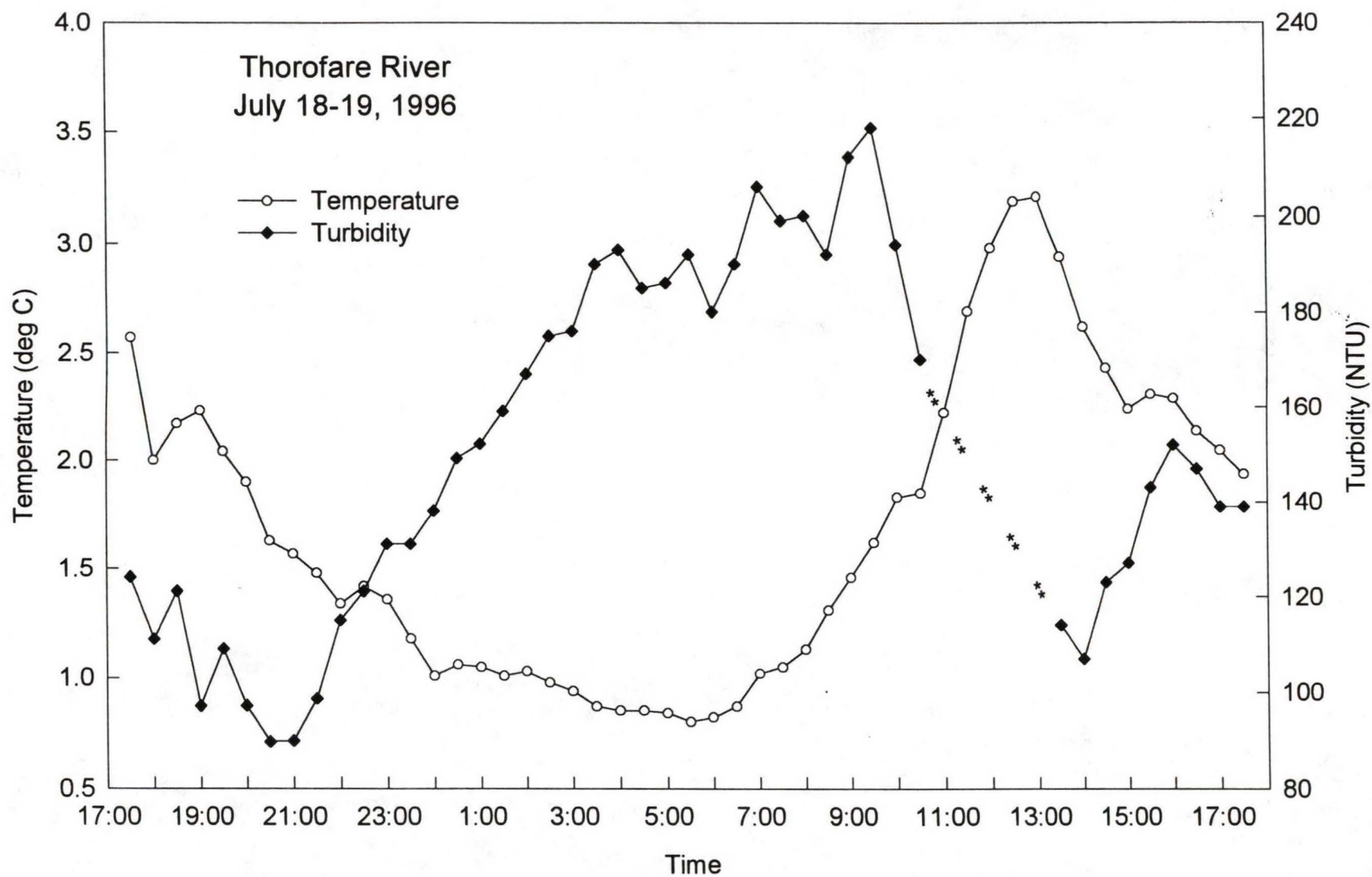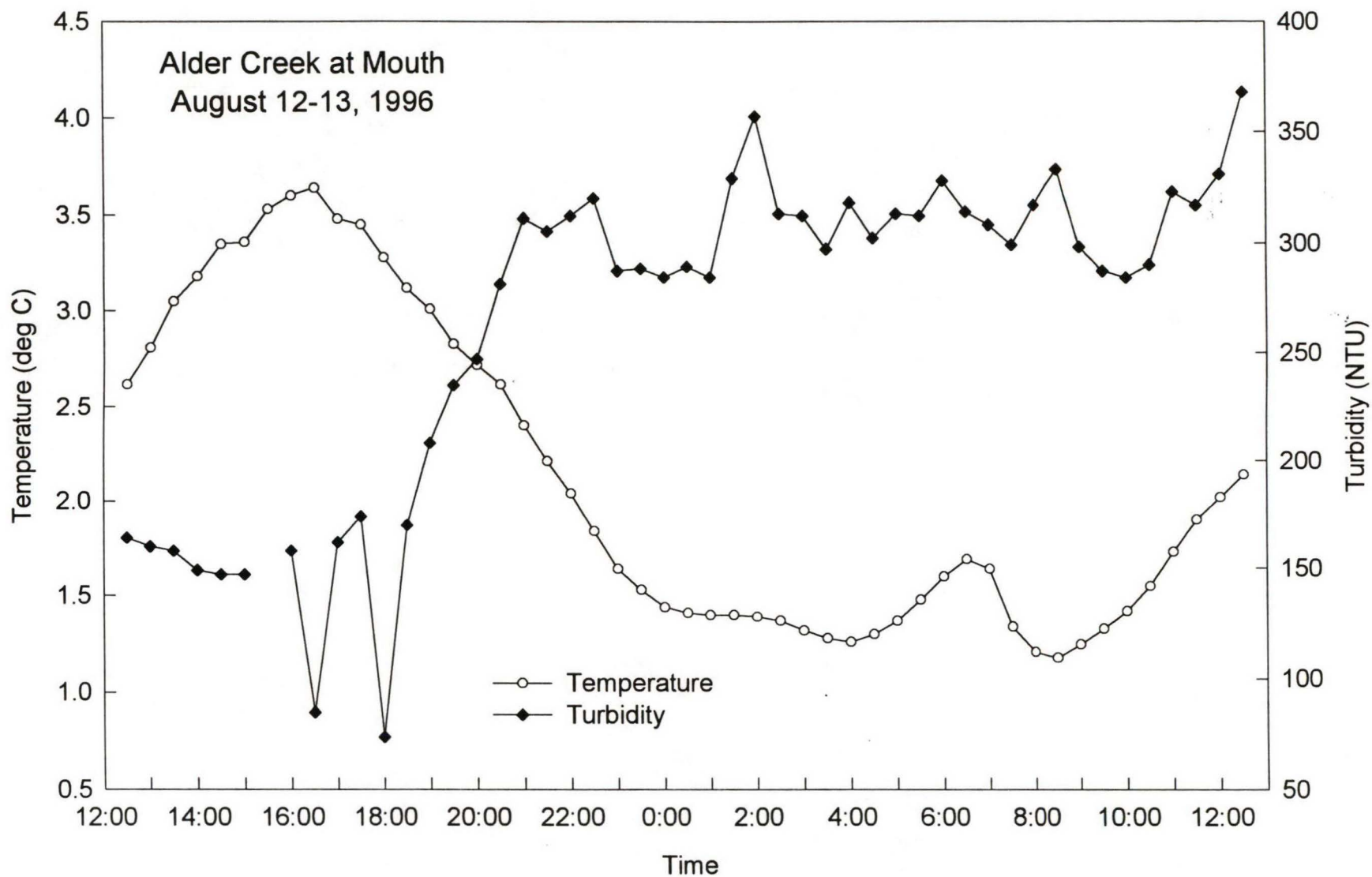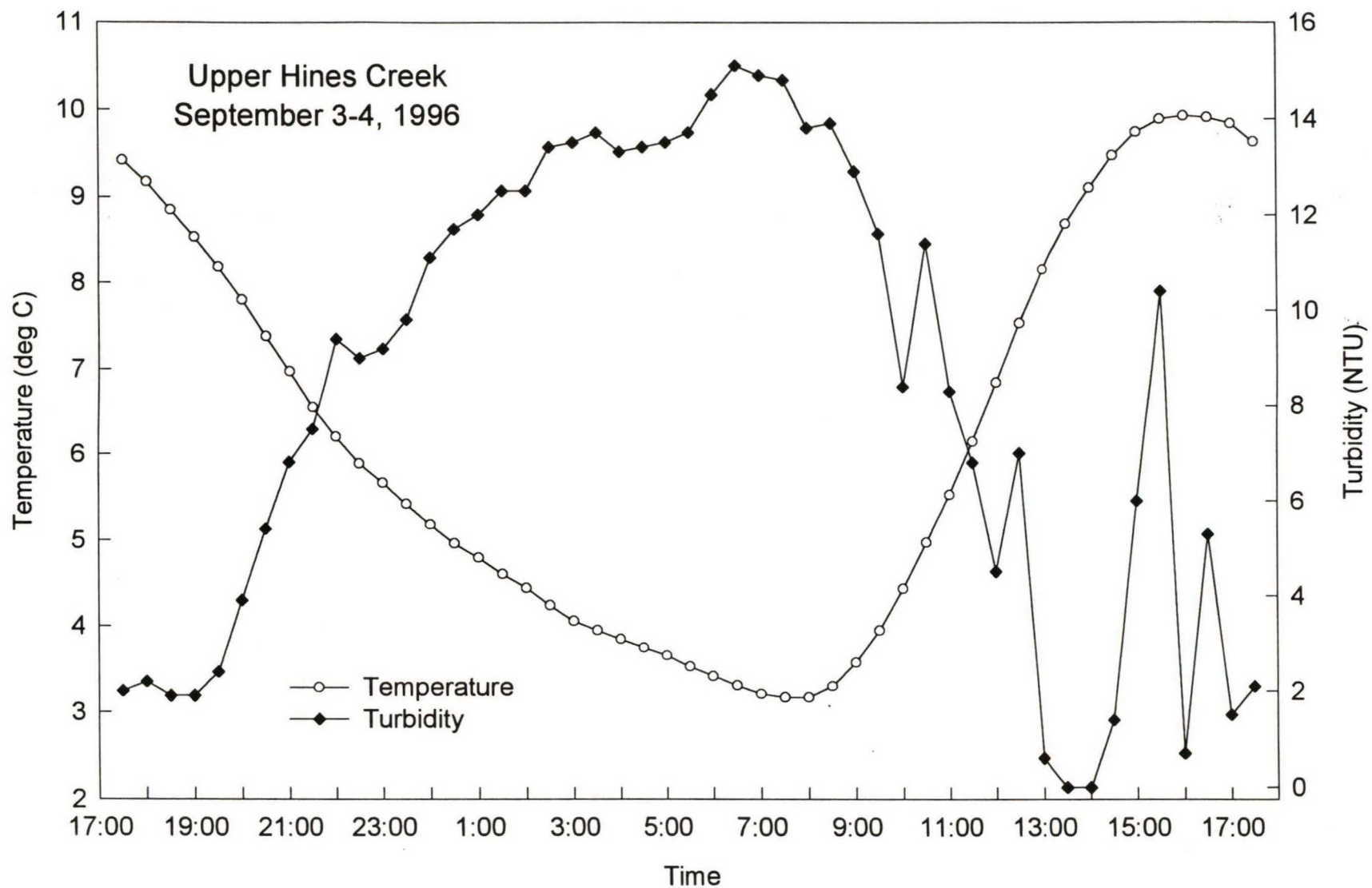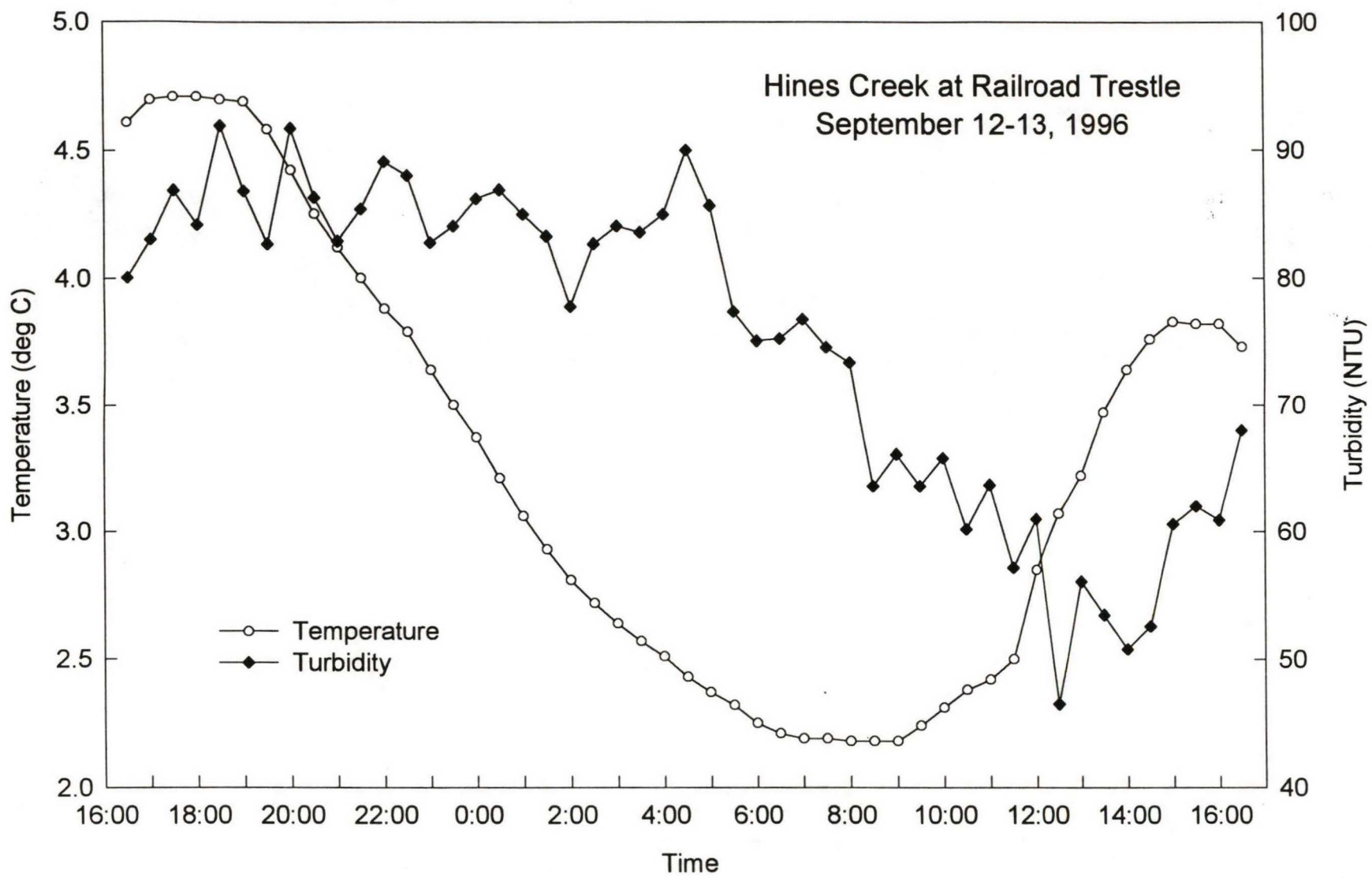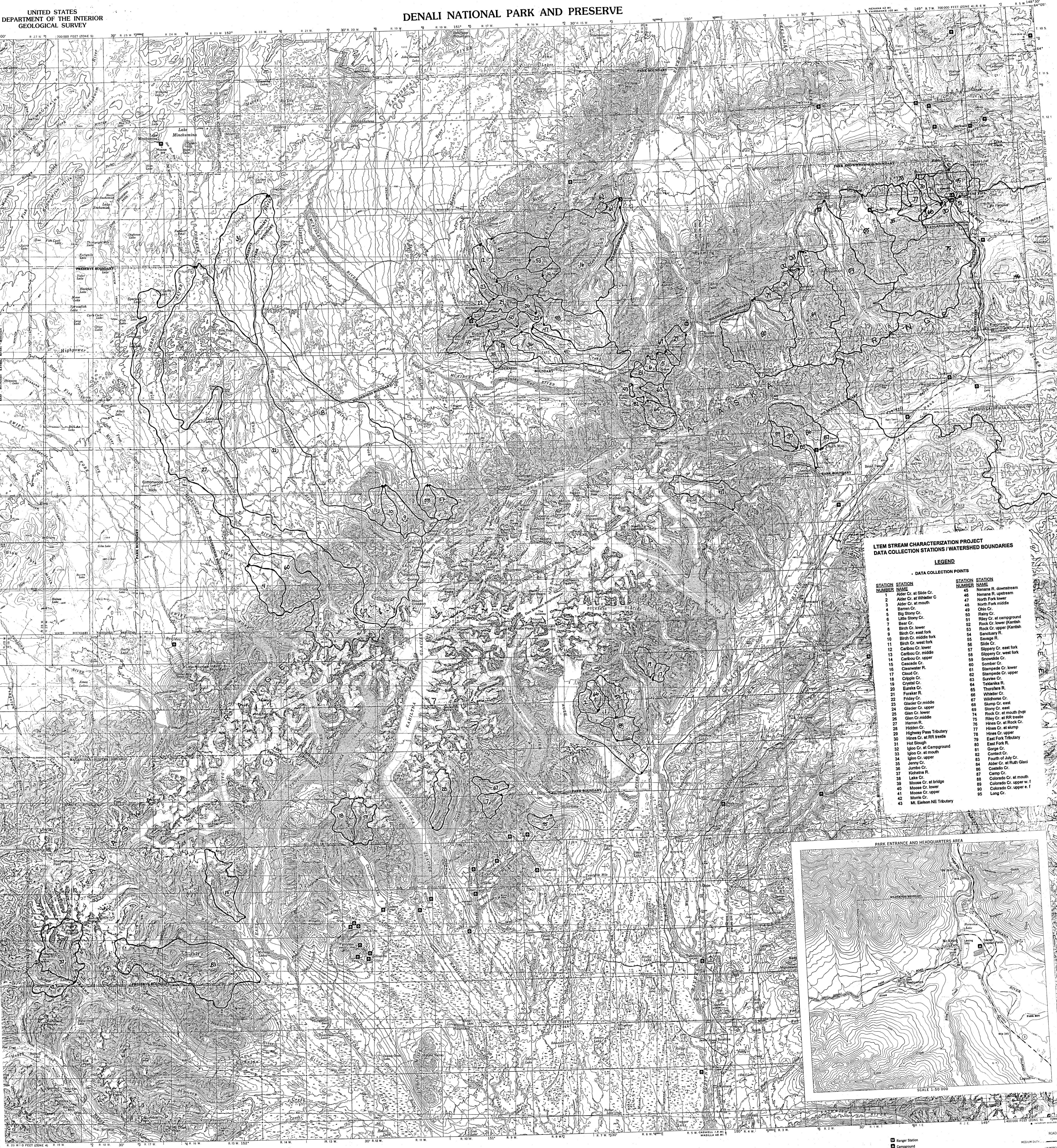
LTEM STREAM CHARACTERIZATION PROJECT
DATA COLLECTION STATIONS / WATERSHED BOUNDARIES

LEGEND

• DATA COLLECTION POINTS

STATION NUMBER	STATION NAME	STATION NUMBER	STATION NAME
1	Alder Cr. at Slide Cr.	45	Nenana R. downstream
2	Alder Cr. at Whistler C	46	Nenana R. upstream
3	Alder Cr. at mouth	47	North Fork lower
4	Barren Cr.	48	North Fork middle
5	Big Stony Cr.	49	Ohio Cr.
6	Little Stony Cr.	50	Rainy Cr.
7	Bear Cr.	51	Riley Cr. at campground
8	Birch Cr. lower	52	Rock Cr. lower (Kantish
9	Birch Cr. east fork	53	Rock Cr. upper (Kantish
10	Birch Cr. middle fork	54	Sanctuary R.
11	Birch Cr. west fork	55	Savage R.
12	Caribou Cr. lower	56	Slide Cr.
13	Caribou Cr. middle	57	Slippery Cr. east fork
14	Caribou Cr. upper	58	Slippery Cr. west fork
15	Cascade Cr.	59	Snowslide Cr.
16	Clearwater R.	60	Somber Cr.
17	Cloud Cr.	61	Stampede Cr. lower
18	Cripple Cr.	62	Stampede Cr. upper
19	Crystal Cr.	63	Sunrise Cr.
20	Eureka Cr.	64	Teklanika R.
21	Foraker R.	65	Thorofare R.
22	Friday Cr.	66	Whistler Cr.
23	Glacier Cr. middle	67	Wildhorse Cr.
24	Glacier Cr. upper	68	Slump Cr. east
25	Glen Cr. lower	69	Sunrise Cr. east
26	Glen Cr.middle	74	Rock Cr. at mouth (hdr
27	Herron R.	75	Riley Cr. at RR trestle
28	Hidden Cr.	76	Hines Cr. at Rock Cr.
29	Highway Pass Tributary	77	Hines Cr. at slump
30	Hines Cr. at RR trestle	78	Hines Cr. upper
31	Hot Slough	79	East Fork Tributary
32	Igloo Cr. at campground	80	East Fork R.
33	Igloo Cr. at mouth	81	Gorge Cr.
34	Igloo Cr. upper	82	Contact Cr.
35	Jenny Cr.	83	Fourth of July Cr.
36	Jumbo Cr.	84	Alder Cr. at Ruth Glaci
37	Kidnatna R.	85	Costello Cr.
38	Lake Cr.	86	Camp Cr.
39	Moose Cr. at bridge	88	Colorado Cr. at mouth
40	Moose Cr. lower	89	Colorado Cr. upper w. f
41	Moose Cr. upper	90	Colorado Cr. upper e. f
42	Morts Cr.	95	Long Cr.
43	Mt. Eielson NE Tributary		

PARK ENTRANCE AND HEADQUARTERS AREA

SCALE 1:50 000

SCALE 1:250000

CONTOUR INTERVAL 200 FEET
DOTTED LINES REPRESENT 100-FOOT CONTOURS
NATIONAL GEODETIC VERTICAL DATUM OF 1929

1985 MAGNETIC DECLINATION FROM TRUE NORTH VARIES FROM 24° (427 MILS) EASTERLY FOR THE
CENTER OF THE WEST EDGE TO 26° (462 MILS) EASTERLY FOR THE CENTER OF THE EAST EDGE

LOCATION INDEX

QUADRANGLE LOCATION

PARK AND WILDERNESS
PARK
PRESERVE

DENALI NATIONAL PARK AND P

Ranger Station
Campground
Air Strip

ROAD CLASSIFICATIO
MEDIUM DUTY
LIGHT DU
UNIMPROVED DIRT
STATE ROUTE